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Calcium intake and food sources of calcium in adolescents living in the Auckland, Waikato and Bay of Plenty regions of New Zealand

A thesis presented in partial fulfilment of the requirements for the degree of

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Abstract

Background: Adolescence is a time of rapid linear growth and acquisition of bone mass. Adequate calcium intake supports rapid bone growth during this time and is crucial to help prevent osteoporosis later in life. The most recent national nutrition data from over 15 years ago showed inadequate calcium intake in New Zealand (NZ) adolescents. A recent study conducted in Dunedin found that calcium intake in older adolescents was lower than national recommendations. Milk and cheese were found to be the primary sources of calcium in NZ adolescents' diets. This study aims to investigate current calcium dietary intake and food sources of calcium for adolescents living in NZ.

Methods: This cross-sectional study presents a secondary analysis from Te Rourou Kai o Ngā Rangatahi: Eating Patterns of Young People in NZ. Adolescents ($n = 310$) in Auckland, Waikato, and Bay of Plenty regions of NZ, adolescents aged 12 to 18 years participated. Participants completed a demographic questionnaire and Intake24 (an online multiple-pass method 24-hour dietary recall). Data from the recalls was used to obtain calcium intakes and dietary sources of calcium.

Results: The majority of participants were female (66.7%) and identified as Māori (30.3%) or NZ European (27.7%). Calcium intakes (mean $\pm$ SD) were 576 ± 419 mg and 586 ± 444 mg for females and males respectively ($p = 0.845$). The median [IQR] calcium intake for female adolescents was 482 mg [286, 780], and for male adolescents was 463 mg [286, 790] ($p = 0.941$). The prevalence of inadequate calcium intake (based on the calcium estimated average requirement of 1050 mg/day) in females was 88.9% ($n = 184$) and 84.3% ($n = 87$) in males ($p = 0.255$). Predominant food sources of calcium in adolescents were savoury mixed dishes (24.5%), non-alcoholic beverages (18.2%), and milk & milk alternatives (14.6%).

Conclusion: Calcium intake among participants was below the estimated average requirement, indicating a need to promote calcium-rich foods among adolescents. Primary dietary food sources of calcium included mixed dishes and non-alcoholic beverages. Further research with two non-consecutive 24-hour recalls is required to more accurately investigate

calcium intake, particularly in younger adolescents, and the context in which calcium is being consumed to better understand calcium intake in NZ adolescents.

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List of Abbreviations

AI	Adequate intake
AR	Average requirement
BMD	Bone mineral density
BMI	Body mass index
CCHS	Canadian Community Health Survey
CI	Confidence interval
DRI	Dietary reference intake
DRV	Dietary reference value
EAR	Estimated average requirement
EFSA	European Food Safety Authority
EQI	Equity index
FAO	Food and agricultural organization of the United Nations
FFQ	Food frequency questionnaire
IQR	Interquartile range
LRNI	Lower reference nutrient intake
mmol/L	Millimole per litre
MPM	Multiple pass method
NHANES	National health and nutrition examination survey
NRV	Nutrient reference value
NZ	New Zealand
NZEO	New Zealand European
NZANS	New Zealand Adult Nutrition Survey
NZNCNS	New Zealand National Children's Nutrition Survey
PBM	Peak bone mass
PRI	Population reference intake
PTH	Parathyroid hormone
RDA	Recommended dietary allowance
RDI	Recommended dietary intake
RNI	Reference nutrient intake
SD	Standard deviation
UK	United Kingdom
UL	Upper level of intake
USA	United States of America
USDA AMPM	United States Department Agency of Agriculture Automated Multiple-Pass Method
WHO	World Health Organization

Chapter 1: Introduction

1.1 Background

The World Health Organization (n.d.) defines adolescence as the phase of life between childhood and adulthood, from ages 10 to 19 years. During this phase, rapid skeletal growth occurs (Das et al., 2017). Skeletal growth during adolescence helps to achieve maximum peak bone mass (National Health and Medical Research Council et al., 2006). Adequate calcium is necessary to support rapid bone growth.

Calcium is the most abundant mineral in the human body (Gibson, 2005). The majority of calcium in the body (>99%) is found in the skeleton (Rizzoli et al., 2021). Bone acts as a reservoir for calcium, supporting the development and maintenance of bone integrity (Institute of Medicine (US) Committee, 2011). This essential mineral is under tight control to maintain serum calcium levels (Peacock, 2010). Calcium is required in numerous metabolic and hormonal processes (Peacock, 2010), highlighting its importance in maintaining physiological health. During adolescence, calcium requirements increase in response to a higher rate of skeletal calcium accretion (National Health and Medical Research Council et al., 2006), supporting the majority of peak bone mass formation (Mesías et al., 2011). Not achieving peak bone mass during adolescence can increase the risk of developing osteoporosis later in life when bone resorption exceeds bone formation, which commences in the third decade of life (Clarke, 2008). Therefore, achieving calcium requirements during adolescence is critical. Achieving adequate dietary calcium intake in conjunction with sufficient weight bearing exercise and adequate vitamin D intake protects against osteoporosis later in life (Mesías et al., 2011; Rizzoli et al., 2021).

Data from New Zealand (NZ) nutrition surveys determined that adolescents are not achieving the daily calcium intake requirements, based on calcium's estimated average requirement of 1,050 mg/day (National Health and Medical Research Council et al., 2006). The NZ National Children's Nutrition Survey (NZNCNS) included young adolescents aged 10 to 14 years, which was conducted over 20 years ago by the Ministry of Health (2003). The

daily calcium intake among 11 to 14 year olds was 733 mg in females and 888 mg in males (Ministry of Health, 2003). The NZ Adult Nutrition Survey (NZANS) and the SUNDIAL Study, which included older adolescents (aged 15 to 18 years), both found that fewer than half of adolescents achieve adequate amounts of daily dietary calcium intake (Henderson, 2021; University of Otago and Ministry of Health, 2011). The mean calcium intake in adolescents from the NZANS was 724 mg in females (87.8% inadequate intake) and 1,035 mg in males (57.7% inadequate intake) (University of Otago and Ministry of Health, 2011). In more recent years, The SUNDIAL Study identified inadequate calcium intake in 85% of female and 63% of male adolescents (Henderson, 2021). Overall, these findings suggest that a high percentage of NZ adolescents have inadequate intakes of calcium. Inadequate calcium intake is a concern as it limits adolescents from achieving peak bone mass during these early years and increases the prevalence of developing osteoporosis later in life (Weaver et al., 2016).

Calcium requirements can be met through a variety of calcium-rich dietary sources. Good sources of calcium include cow's milk and dairy products, tinned fish with bones, leafy green vegetables, and fortified plant-based milks (e.g., soy and rice milks) (Gibson, 2005). The NZNCNS and NZANS found the primary food group that contributed to dietary calcium intake in young and older adolescents was dairy, more specifically milk (e.g., cow, soy, rice, goat, and flavoured milk) (Ministry of Health, 2003; University of Otago and Ministry of Health, 2011). Similarly, the SUNDIAL Study also determined that milk was the largest contributor to calcium in the diet, regardless of whether the dietary pattern was omnivorous or vegetarian (Henderson, 2021). Other primary sources of calcium found in the NZANS, NZNCNS, and SUNDIAL study were bread (not including bread-based dishes) and non-alcoholic beverages (e.g., tea, coffee, hot chocolate drinks, juices, etc.) (Henderson, 2021; Ministry of Health, 2003; University of Otago and Ministry of Health, 2011).

As the last NZ national nutritional survey was conducted over 15 years ago, this data is outdated. However, the available data highlights the importance of assessing adolescents' calcium intake and the main dietary sources of calcium.

1.2 Purpose of the Study

Currently, there are limited data regarding calcium intakes and calcium food sources in adolescents living in New Zealand, particularly data in recent years. This study aims to describe calcium intakes and calcium food sources in adolescents aged 12 to 18 years living in the Auckland, Waikato and Bay of Plenty regions of New Zealand. Furthermore, the study will determine if adolescents are meeting calcium requirements. The findings of this research will allow for a better understanding and updated data of calcium intake and dietary food sources of calcium in adolescents in New Zealand.

1.3 Aims and Objectives

Aim: To determine calcium intake and calcium food sources in adolescents aged 12 to 18 years old living in the Auckland, Waikato and Bay of Plenty regions of New Zealand.

Objectives:

- To assess calcium intakes in adolescents using an electronic 24-hour dietary recall (multiple pass method).
- To determine whether New Zealand adolescents are meeting recommendations for calcium intake.
- To evaluate food sources of calcium in adolescents.

1.4 Structure of the Thesis

This thesis consists of four chapters. The introductory chapter provides background evidence to justify the research study and describes the aims and objectives of the study. Chapter two reviews the current literature on calcium. In particular, the literature review highlights the importance of nutrition in adolescence, the role of calcium in the body, calcium recommendations for adolescents, and methods of assessing dietary calcium intake. The current calcium intake for adolescents in New Zealand and similar developed countries, and the primary contributors to food sources of calcium are described. Chapter three is a

research manuscript that outlines the rationale for conducting the study, the aim of the study, the methods and results, and a discussion of the study findings. Chapter four presents the main findings of the study, which are then discussed and concluded by outlining the strengths, limitations, and recommendations for further research.

1.5 Researcher's Contributions

Researchers	Contribution to the research
Annabelle Urquhart	MSc Nutrition and Dietetics candidate. Primary author of this thesis, involved in most components of research including developing the participant information sheet for the Eating Patterns of Young People in NZ Study, data collection, sending out invitations to participants to complete a 24-hour diet recall, dietary data analysis, interpretation of results, writing, editing and submission of thesis.
Professor Cath Conlon	Main academic supervisor for the calcium intake and food sources of calcium study, co-investigator of the Eating Patterns of Young People in NZ Study.
Professor Kathryn Beck	Co-academic supervisor for the calcium intake and food sources of calcium study, lead-investigator of the Eating Patterns of Young People in NZ Study. Application for research ethics, and development of the Eating Patterns of Young People in NZ Study protocol.
Dr Jamie de Seymour	Co-supervisor and co-investigator of the Eating Patterns of Young People in NZ. Application for research ethics, development of the Eating Patterns of Young People in NZ Study protocol, lead researcher for data collection.
Laurie Wharemate-Keung and Juanita Maaka	Involved in the recruitment of schools.
Karen Mumme	Guidance on statistical analysis and data cleaning.
Jessica Barrar	Data collection from participants.
Cate Davis and Ruby Young	Participant recruitment and research assistants.

Chapter 2: Literature Review

2.1 Introduction

This chapter reviews and evaluates all relevant literature regarding calcium with a focus on calcium intake and dietary sources of calcium in adolescents living in New Zealand. Updated research on calcium intake and dietary sources of calcium in New Zealand adolescents is necessary to guide nutrition interventions to prevent inadequate calcium intake in adolescents. Assessing dietary calcium intake and where adolescents obtain calcium in their diet could highlight areas for intervention, as existing national literature highlights many adolescents in New Zealand do not meet recommended calcium requirements. This literature review focuses on the importance of nutrition for adolescents, the role of calcium in the body in states of health and deficiency, recommended intakes of calcium during adolescence, and evaluates methods of assessing dietary calcium intake. The chapter concludes with reviewing adolescent calcium intake, and major food sources of calcium contributing to an adolescent's diet in New Zealand and in similar developed countries.

2.2 Search Strategy

Discover (a Massey University library database), Scopus, Google Scholar, and Pubmed databases were searched using key words between October 2023 and June 2025. Search criteria key words were based on the study objectives: calcium OR "calcium intake" OR "calcium source*" OR adolescen* OR "secondary school" OR teen* OR "high school*" OR adequacy OR milk OR cheese OR yogurt OR dairy OR "New Zealand" OR NZ OR Aotearoa OR "developed countries". Only papers published in English and written after 1990 were included.

2.3 Importance of Nutrition in Adolescence

Adolescence is a critical period of growth and development (Das et al., 2017). During this phase there is an increased demand for nutrients to support bone mineralisation, cognitive growth and development, muscle and fat mass accrual (Soliman et al., 2014), immunity, and maturation of sex organs (Norris et al., 2022). Poor dietary habits during adolescence can lead to nutritional deficiencies (Norris et al., 2022). Inadequacies in nutritional status can affect adolescents' growth, onset and duration of puberty, and increases the risk of non-communicable diseases such as obesity, cardiovascular disease, and osteoporosis later in life (Norris et al., 2022). Hormonal changes during puberty increase adolescents' nutritional requirements for macronutrients, vitamins and minerals (Soliman et al., 2014). A key nutrient of concern for adolescents is calcium.

2.4 Role of Calcium in the Body

Calcium is an essential nutrient that is predominately found in the bone and teeth to provide structural support. Furthermore, calcium plays a critical role for many other essential physiological processes including enzyme activation, muscle contraction, neurotransmission, vesicular secretion, blood coagulation, secretory activity, immune response, cellular aggregation, transformation, and cell division (Diaz de Barboza et al., 2015; Peacock, 2010; Theobald, 2005; Weaver & Heaney, 2007). As a result of these physiological roles calcium concentration is tightly regulated to maintain homeostasis. Food sources of calcium include dairy products, vegetables, calcium fortified products, fish with bones, legumes, and nuts and seeds (National Institutes of Health, 2022)

Calcium is a component of hydroxyapatite crystals, $\text{Ca}_{10}(\text{OH})_2(\text{PO}_4)_6$ (Mann & Truswell, 2012). Calcium hydroxyapatite crystals are the most abundant form of calcium (Institute of Medicine (US) Committee, 2011). More than 99% of calcium hydroxyapatite crystal reserves are found in the bone matrix and teeth, contributing to rigidity (Rizzoli et al., 2021). The

other remaining <1% of calcium is found in the blood, muscle, and other tissues (Institute of Medicine (US) Committee, 2011).

Normal total calcium in serum has a narrow range between 2.15 mmol/L to 2.57 mmol/L, this value accounts for calcium that is not stored in the bone and assumes a normal serum albumin measure (Raymond & Morrow, 2020). Calcium is tightly controlled to maintain extracellular calcium homeostasis, transferring calcium ions found in the bone reservoir to serum when serum calcium falls below normal concentration (Mesías et al., 2011).

Consequently, calcium in the serum is maintained at the expense of bone mass (Mesías et al., 2011). The continuous process of bone remodelling of resorption and formation is controlled by osteoclasts and osteoblasts (Florencio-Silva et al., 2015). During adolescence, bone formation precedes bone resorption (Clarke, 2008).

The parathyroid hormone (PTH) and calcitonin are complementary calciotropic hormones which are involved in calcium metabolism via negative feedback loops. When limited serum calcium concentrations are circulating, the PTH signals a rapid release of calcium from the bone to increase serum calcium by activating osteoclasts (Leko et al., 2021). During elevated concentrations of circulating serum calcium, calcitonin decreases the amount of serum calcium by inhibiting osteoclasts and enabling calcium to be utilised in the bones (Carter & Schipani, 2006).

Calcium absorption is highly regulated by vitamin D (25-hydroxyvitamin D (25[OH]D)). Both micronutrients play a role in bone health, as vitamin D helps with calcium absorption. Calcium is transported via active or paracellular transport in the intestines. Adequate vitamin D status facilitates calcium absorption rates to increase to 30 to 40% in the intestines (Holick, 2007). During states of vitamin D deficiency, bone mineralisation may be impacted as calcium absorption rates decline to 10 to 15% (Khazai et al., 2008).

The Importance of Calcium Intake during Adolescence

Calcium is required for the development of peak bone mass (PBM) during adolescence (National Health and Medical Research Council et al., 2006). PBM is the maximal amount of bone tissue present at the end of skeletal maturation. PBM is usually achieved between 20 to 30 years of age (Baxter-Jones et al., 2011). Approximately 45 to 50% of total adult skeletal mass is completed during adolescence, with close to 95% of total adult bone mass reached by 18 years of age (Baxter-Jones et al., 2011). The significant development of skeletal bone mass during adolescence highlights the importance of calcium during this phase of life. Lifestyle factors such as weight-bearing physical activity, adequate vitamin D intake, and adequate calcium intake promote bone accretion to help maximise bone mineral density (BMD) (Mesías et al., 2011). After PBM has been achieved in early adulthood, BMD continues to remodel and there is a balance between resorption and formation (Clarke, 2008).

In later adulthood, bone resorption precedes bone formation from the influence of hormonal changes. Meeting age specific calcium and vitamin D nutrient reference values during adolescence can reduce the incidence of low BMD and osteoporosis later in life. Osteoporosis is directly translated to “porous bone” which is characterised by reduced bone mass, loss of bone tissue integrity and disruption of bone structure (Sözen et al., 2017). This deterioration in bone mass predisposes individuals to an increased risk of fractures (Pouresmaeili et al., 2018). Osteoporosis is associated with older populations due to the steady decline in bone mass during adulthood, in particular postmenopausal women (Pouresmaeili et al., 2018). During the menopausal stage, up to 20% of bone mineral density loss can occur (Ji & Yu, 2015). Menopause influences the body’s production of hormones, thus affecting hormone levels and increases bone reabsorption. In 2007, it was estimated that over 70,000 NZ individuals had been diagnosed with osteoporosis based on data from the NZ Health Survey and NZ Census (Brown et al., 2011). No recent data regarding osteoporosis diagnoses in NZ has been reported, however osteoporosis diagnoses have continued to rise worldwide and are predicted to continue to rise due to the longer lifespan of an aging population (International Osteoporosis Foundation, 2021). The International Osteoporosis Foundation (2021) shows that approximately 20% of males and more than 30%

of females over the age of 50 years will experience an osteoporotic fracture. Osteoporosis affects an individual's quality of life and increases mortality rate (Sözen et al., 2017).

2.5 Calcium Recommendations for Adolescents

Calcium requirements consider the amount of dietary calcium needed to maintain calcium homeostasis. Calcium homeostasis is estimated by the amount of calcium that is needed to be absorbed to meet calcium losses (1mmol calcium = 40mg calcium) (National Health and Medical Research Council et al., 2006). Table 2.1 compares adolescents' daily calcium (mg/day) dietary recommendations in New Zealand and other developed countries. Although, these values are expressed as a per day basis, nutrient intakes need to be assessed over a three or four days to account for variability in an individual's dietary intake (National Health and Medical Research Council et al., 2006).

Nutrient Reference Values (NRV) are recommendations for dietary intakes required for healthy individuals (National Health and Medical Research Council et al., 2006). Across other nations, NRV are known by an alternative terminology name for example, in the United Kingdom (UK) NRV are referred to as Dietary Reference Values (DRV), whereas in the United States of America (USA) it is referred to as the Dietary Reference Intake (DRI) (Gibson, 2005). Nutrient recommendations and requirements vary between countries and some use guidelines set by the World Health Organization (WHO) and Food Agricultural Organization (FAO) as a reference for their own countries' dietary guidelines. The WHO and FAO guidelines are implemented to promote human health by reducing the risk of chronic diseases and prevent deficiencies or malnutrition (Food and Agriculture Organization of the United Nations, 2024).

Table 2.1. Adolescents' daily calcium (mg/day) dietary recommendations in New Zealand and other developed countries.

	New Zealand and Australia 2006 (National Health and Medical Research Council et al., 2006)	USA and Canada 2011 (Institute of Medicine (US) Committee, 2011)	United Kingdom 1991 (Department of Health, 1991)	European Food Safety Authority (EFSA) for the European Union* 2015 (European Food Safety Authority, 2015)
Daily dietary calcium recommendations ¹ (mg/day)	<u>RDI</u> Females and males 9 to 11 years: 1,000 12 to 13 years: 1,300 14 to 18 years: 1,300	<u>RDA</u> Females and males 9 to 13 years: 1,300 14 to 18 years: 1,300	<u>RNI</u> Females 10 years: 550 11 to 14 years: 800 15 to 18 years: 800 Males 10 years: 550 11 to 14 years: 1,000 15 to 18 years: 1,000	<u>PRI</u> Females and males 4 to 10 years: 800 11 to 17 years: 1,150 18 to 24 years: 1,000
Average Requirement (mg/day)	<u>EAR</u> Females and males 9 to 11 years: 800 12 to 13 years: 1,050 14 to 18 years: 1,050	<u>EAR</u> Females and males 9 to 18 years: 1,100	<u>EAR</u> Females 7 to 10 years: 425 11 to 14 years: 625 15 to 18 years: 625 Males 7 to 10 years: 425	<u>AR</u> Females and males: 4 to 10 years: 680 11 to 17 years: 960 18 to 24 years: 860

	New Zealand and Australia 2006 (National Health and Medical Research Council et al., 2006)	USA and Canada 2011 (Institute of Medicine (US) Committee, 2011)	United Kingdom 1991 (Department of Health, 1991)	European Food Safety Authority (EFSA) for the European Union* 2015 (European Food Safety Authority, 2015)
			11 to 14 years: 750 15 to 18 years: 750	
Upper Level of Intake (UL) (mg/day)	Females and males 9 to 13 years: 2,500 14 to 18 years: 2,500	Females and males 9 to 13 years: 3,000 14 to 18 years: 3,000	Females and males 10 to 18 years: 1,500	Not set
Lower Reference Nutrient Intake (LRNI) ² (mg/day)	Not set	Not set	Females 7 to 10 years: 325 11 to 14 years: 450 15 to 18 years: 450 Males 7 to 10 years: 325 11 to 14 years: 450 15 to 18 years: 480	Not set

Abbreviations: AR, Average Requirement; EAR, Estimated Average Requirement; LRNI, Lower Reference Nutrient Intake; RDA, Recommended Dietary Allowance; RDI, Recommended Dietary Intake; RNI, Reference Nutrient Intake; PRI, Population Reference Intake; UL, Upper Level of Intake; USA, United States of America.

*European Food Safety Authority nutrient reference values are used as a reference framework for multiple European Union countries.

¹Dietary calcium recommendations refer to the Recommended Dietary Intake (RDI), or Recommended Dietary Allowance (RDA), Reference Nutrient Intake (RNI), or Population Reference Intake (PRI).

²Lower Reference Nutrient Intake (LRNI) is a nutrient reference value used only in the United Kingdom and describes the amount of a nutrient that is adequate for only 2.5% of the population with low requirements (Department of Health, 1991).

The Recommended Dietary Intake (RDI) is terminology used in New Zealand and Australia to describe the average daily dietary intake level that is adequate to meet the nutrient requirements of almost all healthy individuals at a particular life stage and sex. Terminology for RDI in USA and Canada is referred to as Recommended Dietary Allowance (RDA) (Institute of Medicine (US) Committee, 2011), the Reference Nutrient Intake (RNI) in the United Kingdom (Department of Health, 1991), and Population Reference Intake (PRI) in Europe (European Food Safety Authority, 2017). In Table 2.1, the RDI, RDA, RNI, and PRI is provided for dietary calcium. The RDI for calcium for adolescents in Australia and NZ aged 12 to 18 years is 1,300 mg/day (National Health and Medical Research Council et al., 2006). Adolescents between 12 to 18 years old have the greatest RDI for calcium across all age groups to account for rapid rates of growth. The Department of Health (1991) set up the United Kingdom's dietary calcium recommendations over 30 years ago. The UK's dietary calcium recommendations are the lowest for ages 11 to 18 years when compared against Australian & New Zealand, USA & Canada, and the European Food Safety Authority (EFSA). The EFSA nutrient reference values are used as a reference framework for multiple European Union countries.

The estimated average requirement (EAR) is the requirement to meet the needs of half the healthy individuals at a particular life stage and sex. Estimated average requirement is also known as the average requirement (AR) (National Health and Medical Research Council et al., 2006) and grouped under Average Requirement in Table 2.1. The EAR for calcium in adolescents in NZ, aged 12 to 18 years is 1,050 mg/day (National Health and Medical Research Council et al., 2006).

The upper level of intake (UL) is defined as the highest mean daily nutrient intake level for almost all individuals in the general population which is likely to cause no adverse health effects (National Health and Medical Research Council et al., 2006). If the intake of a particular nutrient exceeds the UL, the risk of adverse effects increases (National Health and Medical Research Council et al., 2006). The UL for calcium for all age groups (excluding 0 - 12 months of age) in NZ is set at 2,500 mg/day (National Health and Medical Research Council et al., 2006). The UL is implemented to prevent hypercalcaemia which can lead to kidney stones and to prevent interference of calcium with zinc and iron absorption (National Health

and Medical Research Council et al., 2006). The USA and Canada have a 3,000 mg/day upper level of calcium intake for adolescents, which is an additional 500 mg/day compared with other age groups (Institute of Medicine (US) Committee, 2011). An UL for the EFSA has not been set.

Dietary recommendations of nutrients differ between countries. Many countries use WHO and FAO recommendations, whilst considering their country's public health policies, nutrition priorities, food production and systems, food composition data and food supply (Food and Agriculture Organization of the United Nations, 2024). Countries evaluate their local environment concerns to develop sustainable dietary guidelines to set nutrition guidelines (World Health Organization & Food and Agriculture Organization of the United Nations, 2019). The interpretation of current scientific evidence from comparable countries with similar demographics, population groups, and dietary patterns are further considered when setting a country's Nutrient Reference Values (NRV) (World Health Organization & Food and Agriculture Organization of the United Nations, 2004). The NRV of calcium for Australia and New Zealand were determined as part of a joint initiative of the New Zealand Ministry of Health, Australian National Health and Medical Research Council, and Australian Government Department of Health and Ageing (National Health and Medical Research Council et al., 2006).

2.6 Assessing the Dietary Intake of Calcium

The amount of food and beverages consumed can be estimated using various methods for individuals and populations. Common dietary assessment methods to determine calcium intake include the 24-hour dietary recall, food frequency questionnaire (FFQ), diet history and dietary record (Shim et al., 2014). Dietary assessment methods are discussed below in Table 2.2.

The study design needs to be considered when determining the most suitable dietary assessment method. The study design needs to consider whether dietary changes over time are measured or whether a snapshot dietary intake is assessed. Furthermore, it is important to identify what is being observed e.g., a particular nutrient, ingredient, food group, or dietary pattern. Other factors to consider when choosing a dietary assessment method include; respondent burden, cognitive difficulty, memory requirements of participants, measurement error, resourcing (time and costs) and the time allowed to complete assessments with individuals (Bailey, 2021).

Table 2.2. Summary of the Advantages and Limitations of Dietary Assessment Methods (modified from Shim et al. (2014))

Method of Assessment	Description of Method	Advantages	Limitations
Diet Record	Log of food and beverages intake for a specific period. Can be weighed or estimated.	- Detailed and accurate dietary intake. - No interviewer required. - No recall bias. - Open ended survey.	- Time consuming. - High participant burden (literacy, time consuming and high level of motivation required). - Participants may under or over report.
24-hour Dietary Recall	Participant recalls all food and beverages consumed over the previous day or past 24 hours.	- Inexpensive. - Quick. - Low participant burden. - Recall is often completed by a trained professional either face to face or telephone interview. - Suitable for illiterate participants. - Open ended survey.	- Relies on participants memory. - Participants may over or underestimate intake. - One recall may not be a good representation of usual diet.
Diet History	Usual intake of food and beverages is estimated over a long period of time by determining participants eating pattern.	- Assesses usual food and beverage intake in detail. - Can account for seasonal variability.	- Time consuming for participants. - No set protocol for collecting information for a diet history. - Participants may under or over report.

Food Frequency Questionnaire (FFQ)	Questionnaire for participants regarding foods or food groups consumed over a set period and may or may not include quantities of food consumed.	- Low participant burden. - Can highlight low intakes of specific nutrients.	- Questionnaire needs to be validated. - Participants may overestimate or underestimate intake.
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2.6.1 Diet Record

The 'gold standard' dietary assessment method is the weighed diet record. The weighed diet record is the most reliable in estimating actual habitual dietary intakes (Gibson, 2005). A diet record is a weight log of all food and beverages intake for a specific period. Ideally, a diet record includes three consecutive days: two weekdays and one weekend day to account for any changes in a diet across the week (Gibson, 2005). A three-day weighed diet record can determine accurate quantifiable measurements of food and accounts for multiple days to account for different eating patterns. However, undertaking a three-day weighed diet records puts a high burden on participants due to time required (Gibson, 2005). Diet records can also be estimated which require participants to use standard household measures (e.g., measuring cups and spoons, measurement with a ruler, or counts of a food) (Gibson, 2005). Estimated diet records can lead to inaccuracies if portion sizes are not quantified correctly (Gibson, 2005). Due to the burden of recording weighed or estimated diet records, this may result in dietary changes to eating patterns of participants to simplify the data collected (Gibson, 2005).

2.6.2 The 24-hour dietary recall

The 24-hour dietary recall has high precision and is a valid method to assess energy and nutrient intake (Shim et al., 2014). Individuals recall all food and beverages consumed over the past day or 24 hours (Shim et al., 2014). The 24-hour dietary recall has a structured approach usually conducted by a trained professional. The multiple pass method (MPM) is a standard approach used when undertaking a 24-hour dietary recall. The MPM collects details of food and beverages consumed through the subsequent passes of each stage: quick list; detailed description of the items including portion sizes and commonly forgotten items; and a review and clarification of the recall (Gibson, 2005). This approach helps to prompt memory with each pass, improving accuracy of the diet recall (Gibson, 2005).

Digital methods of the 24-hour dietary recalls reduce interviewer bias, are time effective, and do not require trained interviewers (Castell et al., 2015). A frequent digital method used for the 24-hour dietary recall is the United States Department of Agriculture Automated

Multiple-Pass Method (USDA AMPM) using 5 steps (Blanton et al., 2006). The USDA AMPM has been used in the USA National Health and Nutrition Examination Survey's (NHANES) and other investigations. USDA AMPM simplifies information gathering to ensure suitability on large scale studies (Blanton et al., 2006). Intake24 is an online 24-hour dietary recall tool containing a large database of foods which are linked to composition codes and contains validated portion size images. Intake24 was evaluated and validated on participants 11 years and older against interview led recalls (Bradley et al., 2016). The evaluation of Intake24 in comparison with interview led recalls had similar mean intakes, with energy intake underestimated by 1% and mean macro- and micronutrients were within 4% of interviewer led recalls (Bradley et al., 2016). Intake24 was developed and validated in the United Kingdom, and has since been adapted for multiple countries including a NZ version (Mackay et al., 2025). The Intake24-NZ version was developed by adding a NZ food list that incorporated Māori, Pasifika, and Asian cultural foods and meals (Mackay et al., 2025).

Multiple non-consecutive 24-hour dietary recalls help achieve accurate detailed dietary intakes by providing data on dietary patterns, variability in a diet, and better represents usual intake (Biró et al., 2002; Ma et al., 2009; Shamah-Levy et al., 2016). A single 24-hour dietary recall is not an accurate representation of participants actual diets as diets vary considerably day to day and so are not a reflection of an individual's habitual eating. Nevertheless, a single 24-hour dietary recall has a low respondent burden and is an easy tool to administer in population based research studies (Shim et al., 2014).

2.6.3 Diet history

The diet history, developed over 75 years ago, assesses an individual's usual food and nutrient intake over a long period of time (Morán Fagúndez et al., 2015). The diet history considers a detailed interview on typical eating patterns (e.g., typical breakfast) which may be collected alongside a 24-hour diet recall (Gibson, 2005). Typically, the detail in the diet intake is often cross checked with a three day food record and a FFQ to verify information collected in the interview (Gibson, 2005). This method is frequently used in clinical practice rather than research studies (Morán Fagúndez et al., 2015). This dietary assessment method can be

time consuming to gather and may be difficult to assess with irregular or complex eating patterns (Shim et al., 2014).

2.6.4 Food Frequency Questionnaires

Food frequency questionnaires estimate usual food, nutrient or beverage intakes over a specific period. Various FFQ tools have been developed to examine calcium intake. Magkos et al. (2006) developed and evaluated a FFQ tool to assess calcium intake in the general population across all age groups. Magkos et al. (2006) observed the FFQ tool did not support quantitative assessment for individuals' calcium intakes. The FFQ estimated calcium intake of individuals ranged from 799 mg/day below to 533 mg/day above intake from a 24-dietary recall (Magkos et al., 2006). Other food frequency questionnaires to determine calcium intake have been developed and validated in adolescents (Horiuchi et al., 2019).

Harnack et al. (2006) administered a short FFQ to assess calcium intake on adolescents 11 to 14 years. This short calcium FFQ was shown to be reliable to assess calcium intake in adolescents but had less validity due to underestimating calcium intake. Harnack et al. (2006) identified a moderate association of 0.43 when compared against three 24-hour dietary recalls. Zeyninejad's et al. (2015) study further supported the underestimation of calcium intake with a calcium FFQ tool compared against a 24-dietary recall of children aged 9 to 13 years in Iran. Zeyninejad et al. (2015) observed 36% of children were correctly classified to meet calcium age recommended RDA, 44% were misclassified in adjacent quartiles, and 6% in extreme quartiles. Conversely, Bertoli's et al. (2005) FFQ tool compared against a seven-day food weighted record, and Moore et al. (2007) employed a different dietary assessment method of a rapid assessment method of FFQs in adolescent males, both studies reported calcium intake was overestimated in adolescents. However, Horiuchi's et al. (2019) study on Cambodian adolescents found their FFQ tool accounted for 73.3% of calcium intake (compared to 24-dietary recall) and that 81% of subjects were classified into the correct quartile of calcium intake. A larger study from Barr (1994) in urban high school students found a moderate to strong correlation between calcium intake from an FFQ and food record.

Ollberding et al. (2015) investigated a calcium FFQ use in Hispanic, non-Hispanic Black, and non-Hispanic White children and adolescents aged between 5 and 21 years. Good validity and excellent reliability was reported from Ollberding et al. (2015) in 14 to 21 year olds. Furthermore, a study conducted in the United States of America investigated the appropriateness of using a calcium-specific semiquantitative FFQ against the mean of two 24-hour dietary recalls to examine calcium intake in Asian, Hispanic, and White adolescents (Jensen et al., 2004). The short FFQ had good validity for assessing calcium intake (Jensen et al., 2004). These studies support that FFQ have validated in adolescent populations and demonstrate FFQ tools can be adapted to a population being studied (Jensen et al., 2004; Ollberding et al., 2015; Thompson & Subar, 2017). FFQs have limited accuracy to determine calcium intake at an individual level but may be an acceptable tool for populations in epidemiological studies (Sebring et al., 2007).

2.6.5 Under and Over Reporting of Dietary Intake

Self-reported data in dietary assessments methods are subject to inaccuracies due a tendency for participants to under or over report dietary intake. This is widely observed throughout all dietary assessment methods, particularly in adolescent populations. Livingstone et al. (1992) suggested that the reason for misreporting of energy intake is likely due to adolescence perceptions of body weight and body image affecting eating intake and dietary pattern. Jones et al. (2021) additionally identified having self-critical body perceptions (including low self-esteem or body dysmorphia) had a positive correlation with underreporting of energy intake. Consistent with these findings, Bandini et al. (1990) examined the validity of participants self-reported energy intake in obese and non-obese adolescents. Bandini et al. (1990) observed significant underreporting of dietary intakes in both groups. A study conducted by Sichert-Hellert et al. (1998) noted dietary intake was 20% underreported in females and 12% of males aged 14 to 18 years. More recently, Jones et al. (2021) illustrated 67.2% of adolescents diets were underreported during a three-day food diary. Furthermore, underreporting was positively associated with individuals in a lower socioeconomic status, individuals who were overweight or had a perception of being overweight, a desire to weigh less, a history of restrictive diets, and individuals who skipped

mealtimes (Jones et al., 2021). Overreporting was only seen in 1.5% of adolescent's three-day food diaries with no significant differences between males and females .

2.7 Adolescent Calcium Intake in New Zealand and Other Developed Countries

Calcium intake among adolescents in New Zealand and many other developed countries, is frequently below dietary calcium recommendations. The Adult (2008/2009) and Children's (2002) Nutrition Surveys are the most recent national New Zealand nutrition studies. Data from these studies are now dated, as food supply and diets are constantly changing (Vermeulen et al., 2020). Recent attempts for an updated national nutrition survey have been made as new survey tools and methodology were developed in 2021 by the Ministry of Health (2022), however no surveys have been conducted due to lack of funding. Calcium intakes and prevalence of calcium inadequacy from recent studies conducted in New Zealand and other developed countries are displayed in Table 2.3. Inadequate intake of calcium was based on the corresponding countries calcium estimated average requirement (EAR). Table 2.3 defines whether calcium supplements have been considered in each study or only if calcium is sourced from dietary intake.

The New Zealand Adults Nutrition Survey (NZANS) in 2008/2009, observed a mean daily calcium intake for older adolescents (15 to 18 years) of 1,035 mg/day (males) and 724 mg/day (females) (University of Otago and Ministry of Health, 2011). Inadequacy levels of calcium intake in older adolescents was 87.8% for females and 57.7% for males (University of Otago and Ministry of Health, 2011). In the New Zealand National Children's Nutrition Survey (NZNCNS) undertaken in 2002, young adolescents (aged 11 to 14 years) were found to have a median calcium intake of 733 mg/day in females and 888 mg/day in males (Ministry of Health, 2003). Young adolescents had a calcium inadequacy rate of 29.6% and 28.7% in females and males respectively, significantly lower calcium inadequacy rates than older adolescents in New Zealand. Both the NZANS and the NZNCNS estimated the prevalence of calcium inadequacy using the EAR cut-point method (Calcium EAR for 9- to 11-year-olds: 800 mg/day, 12- to 18-year-olds 1,050 mg/day)

In both the NZ national studies, calcium intake between ethnicities differed. Adolescents who identified as New Zealand Europeans (NZEO) across both national studies were found to have the highest calcium daily consumption. Older adolescents who identified as NZEO had

a mean daily calcium intake of 749 mg/day and 1,062 mg/day in females and males respectively (University of Otago and Ministry of Health, 2011). Younger adolescents who identified as NZEO had a median daily calcium intake of 804 mg/day and 987 mg/day in males and females respectively (Ministry of Health, 2003). The ethnicity groups with the highest levels of inadequate intakes were Pasifika and Māori in both young and older adolescents (Ministry of Health, 2003; University of Otago and Ministry of Health, 2011). Inadequacies of calcium intake for Pasifika respondents were lower in younger adolescents (females 77.6%, males 80.1), than older adolescents (females 99.4%, males 87.8%) (Ministry of Health, 2003; University of Otago and Ministry of Health, 2011). In a cross-sectional survey of 2,549 high school students (aged 14 to 21 years) in Auckland, Sluyter et al. (2010) reported on nutrient intake via a self-administered food frequency questionnaire. This cross-sectional survey highlighted that across both sexes; Māori, Pasifika and Asian ethnicities had a lower milligram (mg) of calcium intake per megajoule of energy (mg/MJ) than New Zealand Europeans (Sluyter et al., 2010). Food selections and portion sizes contribute to differences in nutrient intakes between ethnic groups in New Zealand (Sluyter et al., 2010). No correlations were observed between dietary calcium intake and socioeconomic status in the NZ Adult Nutrition survey in 2008/2009 (University of Otago and Ministry of Health, 2011).

In a smaller NZ study known as the SUNDIAL Study (n = 344) undertaken in Dunedin in 2020, Henderson (2021) noted consistent findings with the 2008/2009 NZ Adult Nutrition Survey. Older adolescents (aged 15 to 18 years) had a mean daily calcium intake of 711 mg/day in females and 935 mg/day in males (Henderson, 2021). Rate of inadequate calcium intake (< 1050 mg/day) was 83% in females and 63% in males (Henderson, 2021).

Adolescents' calcium inadequacy rates found in Australian Health Survey were comparable to findings from New Zealand surveys. The Australian Health Survey (Australian Bureau of Statistics, 2011) found that in young adolescents (aged 12 to 13 years) mean calcium intake was 786 mg/day in females and 946 mg/day in males. Calcium inadequacy rates (< 1050 mg/day) for females and males for younger adolescents were 84.4% and 67% respectively (Australian Bureau of Statistics, 2011). Older adolescents (aged 14 to 18 years) calcium intakes were comparable to younger adolescents with a mean of 711 mg/day in females and

912 mg/day in males (Australian Bureau of Statistics, 2011). Calcium inadequacy rates (< 1050 mg/day) for females and males for older adolescents was 90.3% and 71% respectively (Australian Bureau of Statistics, 2011). Another Australian study conducted by Parker et al. (2012) noted most female and male adolescents did not meet RDI for calcium (< 1,300 mg/day) at 14 years (33% met RDI), this rate decreased significantly ($P < 0.05$) as they aged to 17 years (29.2% of adolescents met RDI).

Other developed countries adolescents' calcium intake is comparable to New Zealand and Australia. The National Teens Survey II from Cashman et al. (2022) conducted in Ireland in 2019/2020 identified female calcium inadequacy rate was 88% (mean intake of 666 mg/day), whilst males had a lower calcium inadequacy rate of 48% (mean intake of 965 mg/day) in 13- to 18-year-olds (Cashman et al., 2022) (Calcium inadequacy rate was based on the United States calcium EAR of < 1,100 mg/day). Likewise, results published from the United Kingdom's National Diet and Nutrition Survey (2008/2009 - 2011/2012) collected a four-day estimated food diary in 884 adolescents. Females' calcium intake (mean $\pm$ SD) was 670 ± 253 mg/day and median of 641 mg/day (Bates et al., 2017). Males' reported calcium intake (mean $\pm$ SD) was 889 ± 370 mg/day and median of 818 mg/day (Bates et al., 2017). Bias of data is indicated in United Kingdom's National Diet and Nutrition Survey as a higher proportion of weekend dates are included than week days due to different distributions of days of the week between years 1 and 2 data (Bates et al., 2017). These biases from the United Kingdom's National Diet and Nutrition Survey were aimed to be reduced during year 3 data collection (Bates et al., 2017) but did not significantly affect mean calcium intake.

A large examination of 14- to 18-year-old adolescents living in Canada, compared two nationally representative surveys conducted in 2004 and 2015 (Vatanparast et al., 2020). Higher rates of calcium inadequacies in adolescents were observed in 2015 than 2004 (Vatanparast et al., 2020). The review from the Canadian Community Health Survey (CCHS) in 2015 identified a mean calcium intake in females and males of 770 and 1040 mg/day respectively (Vatanparast et al., 2020). Comparatively the 2004 CCHS reported calcium intake of 900 mg/day in females and 1,250 mg/day in males (Vatanparast et al., 2020). Vatanparast et al. (2020) reported calcium inadequacy rates (< 1,100 mg/day) from

the 2015 CCHS were 85.7% in females and 66% in males. Whilst in the 2004 CCHS, 75.9% in females and 50.8% in males and had inadequate intakes of calcium.

Rippin et al. (2019) reviewed 21 national dietary surveys completed after the year 2000 from European countries. A trend that was observed with most of these national dietary surveys was the mean calcium intakes for adolescents aged between 10 and 18 years were below the WHO reference nutrient intake of 1,300 mg/day. Females and older children had lower calcium reference nutrient intake (RNI) compliance (Rippin et al., 2019). No comparison was made against the calcium EAR due to lack of raw data from studies (Rippin et al., 2019) .

From recent national surveys over the last 25 years in New Zealand and other developed countries, adolescents report low calcium intakes in both sexes. Furthermore, high rates (> 50%) of adolescents do not meet the EAR for their country. Females are of particular concern as they have a higher risk of not meeting their countries corresponding EAR for calcium. Lower calcium intakes in females are likely to be related to overall less food intake reflected by lower energy intake as compared to males (Cashman et al., 2022).

Table 2.3. Calcium Intake and Prevalence of Inadequacy in Adolescents from New Zealand and Other Developed Countries.

Study (year) and Country	Study Population	Dietary Methodology	Estimated Calcium Intakes and Calcium Inadequacy Rates	Study Comments and Limitations
Adult Nutrition Survey (2008/2009) New Zealand (University of Otago and Ministry of Health, 2011)	Age: 15 to 18 years Females n = 373 Males n = 326	24 diet recall and FFQ Included calcium intake from supplements	Calcium intake from dietary calcium only <u>Mean</u> Females: 724 mg/day Males: 1,035 mg/day Māori females: 571 mg/day Māori males: 885 mg/day Pasifika females: 586 mg/day Pasifika males: 730 mg/day NZEO females: 749 mg/day NZEO males: 1,062 mg/day <u>Inadequate intake based on EAR</u> Females: 87.8% Males: 57.7% Māori females: 95.5% Māori males: 76.1% Pasifika females: 99.4% Pasifika males: 87.8% NZEO females: 85.2% NZEO males: 54.2%	
Children's National Nutrition Survey (2002)	Age: 11 to 14 years	24-hour diet recall	Calcium intake from dietary calcium only <u>Median</u>	

Study (year) and Country	Study Population	Dietary Methodology	Estimated Calcium Intakes and Calcium Inadequacy Rates	Study Comments and Limitations
New Zealand (Ministry of Health, 2003)	Females n = 582 Males n = 576	Included calcium supplements	Females: 733 mg/day Males: 888 mg/day Māori females: 678 mg/day Māori males: 846 mg/day Pasifika females: 524 mg/day Pasifika males: 566 mg/day NZEO females: 804 mg/day NZEO males: 987 mg/day <u>Inadequate intake based on EAR</u> Females: 29.6% Males: 28.7% Māori females: 42.6% Māori males: 27.1% Pasifika females: 77.6% Pasifika males: 80.1% NZEO females: 49.2% NZEO males: 25.2%	
SUNDIAL Study (2020) New Zealand	Age: 15 to 18 years Females n = 243 Males n = 101	Two non-consecutive 24-hour diet recalls	Calcium intake from dietary calcium only <u>Mean</u> Females: 15 - 16 years 752 mg/day	Considered participants level of

Study (year) and Country	Study Population	Dietary Methodology	Estimated Calcium Intakes and Calcium Inadequacy Rates	Study Comments and Limitations
(Henderson, 2021)			17 - 18 years 677 mg/day NZEO 720 mg/day Māori 630 mg/day Pasifika 852 mg/day Asian 616 mg/day Males: 15 - 16 years 893 mg/day 17 - 18 years 941 mg/day NZEO 953 mg/day Māori 1,041 mg/day Pasifika 490 mg/day Asian 802 mg/day <u>Median</u> Females: 711 mg/day (IQR 551, 915) Males: 935 mg/day (IQR 656, 1222) <u>Inadequate intake based on EAR</u> Females: 85% Males: 63%	socioeconomic disadvantage

Study (year) and Country	Study Population	Dietary Methodology	Estimated Calcium Intakes and Calcium Inadequacy Rates	Study Comments and Limitations
Female adolescents (2000) New Zealand (Merrilees et al., 2000)	Age: 15 to 16 years Females n= 91	Three-day diet record and calcium FFQ (gathered at 0, 2 years, and 3 years follow up) Randomised controlled trial	Calcium intake from dietary calcium only <u>Mean</u> Baseline: 765.3 mg/day At two years: 684 mg/day At three years: 652 mg/day	Only included older adolescent females.
Australian Health Survey (2011-2012) Australia (Australian Bureau of Statistics, 2011)	Age: 12 to 18 years Females: 12 to 13 years (n=270) 13 to 18 years (n=688) Males: 12 to 13 years (n=283) 14 to 18 years (n=729)	24-hour diet recall (Automated Multiple-Pass Method)	Calcium intake from dietary calcium only <u>Mean</u> Females 12 - 13 years: 806 mg/day 14 - 18 years: 741 mg/day Males: 12 - 13 years: 945 mg/day 14 - 18 years: 925 mg/day <u>Inadequacy rate based on the EAR</u> Females 12 - 13 years: 84.4% 14 - 18 years: 90.3% Males: 12 - 13 years: 67% 14 - 18 years: 71%	Information collected day before interview Nutrient intake results are estimated of participant's usual diets based on an average of the two 24hour recalls.

Study (year) and Country	Study Population	Dietary Methodology	Estimated Calcium Intakes and Calcium Inadequacy Rates	Study Comments and Limitations
Australian National Children's Nutrition and Physical Activity Survey (2007) Australia (Department of Health and Ageing, 2008)	Ages: 9 to 16 years N = not reported	Cross sectional study Two non-consecutive 24-hour diet recall via three mass method	Calcium intake from dietary calcium only <u>Mean</u> Females: 9 - 13 years: 791.6 mg/day 14 - 16 years: 826 mg/day Males: 9 - 13 years: 988.5 mg/day 14 - 16 years: 1,143.4 mg/day <u>Rate of inadequacy based on the EAR</u> Females: 12 - 13 years: 89% 14 - 16 years: 82% Males: 12 - 13 years: 50% 14 - 16 years: 44%	EAR inadequacy rate based on 2 days of data. Estimated usual intakes.
Dairy food and nutrient intakes in Australian adolescents (2003/2006) Australia	Age: 13 to 18 years Females n = 461 Males: n = 399	Food Frequency Questionnaire (FFQ) Longitudinal observational study. Reported data collected on same adolescents at	Calcium intake from dietary calcium only <u>Mean</u> Follow up at 14 years Females: 1,030 mg/day Males: 1,293 mg/day Follow up at 17 years:	Participants excluded that had unlikely energy intakes. FFQ likely to have

Study (year) and Country	Study Population	Dietary Methodology	Estimated Calcium Intakes and Calcium Inadequacy Rates	Study Comments and Limitations
(Parker et al., 2012)		14 years (13 - 15 years) and 17 years (16 - 18 years) follow up.	Females: 913 mg/day Males: 1,291 mg/day <u>Inadequacy rate based of EAR</u> Follow up at 14 years Females: 58.6% Males: 37.3% Follow up at 17 years Females: 69.4% Males: 40.1% <u>Inadequacy rate based on RDI</u> Follow up at 14 years Females: 76.6% Males: 55.1% Follow up at 17 years Females: 82.4% Males: 57.4%	Likely overestimated calcium intake in the FFQ as frequency data used standardised serving sizes which could result in variability in actual serving sizes consumed.
National Teens Food Survey II (2019-2020)	Age: 13 to 18 years Females n = 216	Four-day weighed diet record	Calcium intake includes dietary calcium and calcium supplements <u>Mean</u>	Considered season of sampling

Study (year) and Country	Study Population	Dietary Methodology	Estimated Calcium Intakes and Calcium Inadequacy Rates	Study Comments and Limitations
Ireland (Cashman et al., 2022)	Males n = 212		Females: 666 mg/day Males: 965 mg/day <u>Median</u> Females: 633 mg/day Males: 926 mg/day <u>5th and 95th percentiles</u> Females: 310 and 1,136 mg/day Males: 493 and 1,565 mg/day <u>Rate of inadequacy based on the EAR</u> Females: 88% Males: 48%	Study included calcium supplement use Rates of inadequacies based on European Food Safety Authority (2015) guidelines.
National Teens Food Survey I (2005-2006) Ireland (Irish Universities Nutrition Alliance, 2006)	Age: 13 to 17 years Females n = 217 Males n = 224	Seven-day semi-weighed food diary Included calcium supplements	Calcium intake from dietary calcium only <u>Mean</u> Females: 734 mg/day Males: 1,063 mg/day <u>Median</u> Females: 678 mg/day Males: 992 mg/day	Considers geographical location, education of parents, and social class.

Study (year) and Country	Study Population	Dietary Methodology	Estimated Calcium Intakes and Calcium Inadequacy Rates	Study Comments and Limitations
National Diet and Nutrition Survey (2008/2009-2011/2012) United Kingdom (Bates et al., 2017)	Age: 11 to 18 years n = 884	Four-day estimated food diary Included calcium supplements	Calcium intake from dietary calcium only <u>Mean</u> Females: 670 mg/day Males: 889 mg/day <u>Median</u> Females: 641 mg/day Males: 818 mg/day <u>Upper 2.5 percentile</u> Females: 1,290 mg/day Males: 1,747 mg/day <u>Lower 2.5 percentile</u> Females: 274 mg/day Males: 372 mg/day <u>% below Lower Reference Nutrient Intake (LRNI)</u> Females: 19% Males: 8%	

Study (year) and Country	Study Population	Dietary Methodology	Estimated Calcium Intakes and Calcium Inadequacy Rates	Study Comments and Limitations
Canadian Community Health Survey (2004/2015) Canada (Vatanparast et al., 2020)	Age: 14 to 18 years Non calcium supplement users 2004 Females n = 1,003,028 Males n = 1,050,793 2015 Females n = 939,325 Males n = 999,614	24-hour diet recall (Automated multiple pass method used) Included calcium supplements	Calcium intake from dietary calcium only 2004 <u>Mean</u> Females: 900 mg/day Males: 1,250 mg/day <u>Inadequacy rate based on the EAR</u> Females: 75.9% Males: 50.8% 2015 <u>Mean</u> Females: 770 mg/day Males: 1,040 mg/day <u>Inadequacy rate based on the EAR</u> Females: 85.7% Males: 66%	Compared 2 nationally representative surveys conducted in 2004 and 2015.

Abbreviations: EAR, estimated average requirement; FFQ, food frequency questionnaire; SEM, standard error of the mean; NZEO, New Zealand European; RDA, recommended dietary allowance; %, percentage.

2.8 Dietary Food Sources of Calcium

Dairy products are a rich source of bioavailable calcium (Melse-Boonstra, 2020).

Rich non-dairy sources of calcium include tinned fish containing edible bones, such as sardines and salmon; calcium-fortified plant-based milks; calcium-set tofu; and selected green vegetables (Gibson, 2005).

See Table 2.4 below for calcium content in selected calcium-rich dietary sources. However, calcium can be added to food and beverages during production or through fortification. For example, tofu may be calcium-set using calcium-based coagulants (Prabhakaran et al., 2006). Fortification of calcium in foods and beverages can help to achieve adequate levels of calcium intake in populations particularly, populations with low calcium intake. The United Kingdom (UK) is the only country to regulate mandatory calcium fortification of wheat flour, it estimates to contribute 13-14% of calcium intake in the UK population (Palacios et al., 2021). Calcium carbonate and tricalcium phosphate are commonly used to fortify foods and beverages as they have been shown to have similar absorption rate compared to calcium in cow's milk (Zhao et al., 2005). In recent years vegan diets have gained in popularity (Alcorta et al., 2021). A systematic review found that people following vegan and vegetarian diets have lower calcium intakes (Bakaloudi et al., 2021). Vegan diets are at risk of being calcium deficient unless a diet is well planned and calcium fortified foods are consumed (Craig, 2009). Calcium absorption rates can vary depending on various factors including vitamin D status (Holick, 2007), phytic acid, oxalic acids (National Health and Medical Research Council et al., 2006), alcohol, and caffeine (Raymond & Morrow, 2020). Therefore, the whole diet needs to be considered as dietary factors may affect the rate of calcium absorbed.

Table 2.4. Calcium Content in Selected Calcium-rich Dietary Sources. Retrieved and Adjusted from the 14th Edition of NZ Food Composition Tables (Plant and Food Research Limited & The Ministry of Health, 2021)

	Per 100 g	Per Serve	
	Calcium (mg)	Portion size	Calcium (mg)
Milk, cow, lite (1.5%), fluid, fresh, composite	120	1 cup (252 g)	291
Cheese, Edam, composite	940	2 cm cube (8 g)	75
Yoghurt, plain, low fat, unsweetened, composite	160	1 cup (257 g)	411
Sardines ¹ , canned in water, drained, composite	340	1 cup (163 g)	554
Salmon ¹ , pink or red, flesh, canned in spring water, drained, composite	270	1 cup (251 g)	678
Soy milk, So Good™ Regular Soy Milk, Sanitarium™, fortified	112	1 cup (255 g)	286
Tofu ² , soy bean curd, regular, firm, simmered or pouched, no salt added, composite	186	1 piece (33.2 g)	62
Spinach, baby leaf, raw, fresh	75	1 cup (26.1 g)	20

¹ Bone inclusion was not specified for sardines and salmon.

² Tofu may be calcium-set; this was not specified in the data.

Milk is the most common source of calcium in western countries including New Zealand. In many developed countries, dairy contributes to close to half of the calcium intake in an individual's diet (Rizzoli et al., 2021). In younger New Zealand adolescents aged 11 to 14 years, milk contributed 31% in females and 35% in males towards their daily calcium intake (Ministry of Health, 2003). In older New Zealand adolescents, aged 15 to 18 years, milk contributed 18.9% in females and 23.2% in males towards their daily calcium intake (University of Otago and Ministry of Health, 2011). However, the 2008/09 New Zealand Adult Nutrition Survey and 2002 National Children's Nutrition Survey classified the milk food group to include dairy milk and non-dairy milk options which may vary in calcium content. Additional major food sources contributing to calcium intake in New Zealand include bread, non-alcoholic beverages (e.g., tea, coffee, hot chocolate drinks, juices etc.), cheese, bread-

based dishes, and other dairy products (e.g., yogurt, ice-cream, sour cream etc.) (Ministry of Health, 2003; University of Otago and Ministry of Health, 2011). Refer to Tables 2.5 & 2.6 below for major dietary food sources of calcium in New Zealand adolescents (Ministry of Health, 2003; University of Otago and Ministry of Health, 2011). Since the last New Zealand Adult Nutrition Survey, Henderson (2021) noted these major dietary sources of calcium remain the most common in older adolescent's (15 to 18 years) diets in New Zealand. Additionally, food groups were similarly distributed in both sexes across New Zealand studies (Henderson, 2021; Ministry of Health, 2003; University of Otago and Ministry of Health, 2011).

Table 2.5. Percentage of Major Calcium Food Sources in the Diet of Females and Males aged 15 to 18 years. Adapted from the 2008/2009 New Zealand Adult Nutrition Survey Methodology Report (University of Otago and Ministry of Health, 2011)

Calcium-rich foods	Females (%)	Males (%)
Milk	18.9	23.2
Bread	10.0	10.1
Non-alcoholic beverages	9.8	8.3
Cheese	7.2	6.6
Vegetables	4.2	3.0
Dairy products	7.2	5.2
Bread based dishes	10.3	12.6
Grains and pasta	5.7	4.6
Fruit	2.5	2.3
Cakes and muffins	3.1	1.1
Fish and seafood	0.7	1.2
Breakfast cereals	1.2	1.5
Sugar and sweets	3.2	1.4
Potatoes, kumara and taro	2.1	2.6
Pies and pasties	1.8	2.8
Eggs and egg dishes	0.9	2.0
Alcoholic beverages	0.9	1.0
Savoury sauces and condiments	1.3	1.1
Poultry	1.5	1.7
Soups and stocks	0.9	0.2
Puddings and Desserts	0.7	0.6
Biscuits	1.3	1.0
Beef and veal	0.8	0.9
Sausages and processed meats	0.8	0.9
Nuts and seeds	0.4	0.4
Pork	0.3	0.6
Snack bars	0.7	0.8
Snack foods	0.7	0.4
Lamb and mutton	0.2	0.1
Butter and margarine	0.1	0.1

Abbreviation: %, percentage.

Table 2.6. Percentage of Major Calcium Food Sources in the Diet of Females and Males aged 11 to 14 years. Adapted from the 2002 National Children’s Nutritional Survey (Ministry of Health, 2003)

Calcium-rich foods	Females (%)	Males (%)
Milk	31	35
Bread	10	10
Dairy products	10	7
Cheese	9	9
Beverages	5	5
Bread based dishes	4	4
Vegetables	3	3
Fruit	3	2
Grains and pasta	3	3
Cakes and muffins	3	2

Abbreviation: %, percentage.

Major food sources in other developed countries are dairy products including milk, cheese, and dairy food. These significant contributors to calcium intake are comparable to New Zealanders diets (see Table 2.7). The 2011/2012 Australian Health Survey reported findings consistent with NZ studies on major calcium food group contributors. Parker et al. (2012) observed a trend between Australian adolescents at a 14 year and 17 year follow up that total dairy intake decreased. Plain milk and flavoured milk significantly decreased in both sexes (Parker et al., 2012). Conversely, cheese products significantly increased from ages 14 years to 17 years (Parker et al., 2012). A secondary analysis of the Australian National Survey in 2007, observed reduced fat dairy options as more common in 14- to 16-year olds than younger adolescents (Baird et al., 2012). Parker et al. (2012) estimated that dairy products contributed 65% towards calcium intake (based on a 300 mg calcium dairy serve) for females at 14 years, decreasing to 61% at 17 years. In males, dairy products contributed 68% towards calcium intake at age 14 years, decreasing to 65% at 17 years. However, Parker et al. (2012) research likely overestimated calcium intake in the FFQ due to obtaining frequency data that used standardised serving sizes which could result in variability in actual serving sizes consumed.

In the National Teens Food Survey II, conducted in Ireland of 13- to 17 year olds; bread and rolls contributed 16.9%; grains, rice, pasta, savouries contributed 10.5%; meat and meat alternatives contributed to 8.4% towards calcium intake (Cashman et al., 2022). Both Ireland national surveys; the National Teens Food Survey I (Irish Universities Nutrition Alliance, 2006) and the National Teens Food Survey II (Cashman et al., 2022) reports similar food group contributions to calcium intake. The Canadian Community Health Survey in 2015 reported grain products making up 12.7% of daily calcium intake, and fruits and vegetables contributing to 10.5% (Vatanparast et al., 2020). Vatanparast et al. (2020) noted the serving sizes of plain milk, flavoured milk, cheese, yogurt, and fortified soy product decreased between the years 2004 and 2015. The 2015 Canadian Health Survey established that 41% of calcium was contributed through milk and milk alternatives (Vatanparast et al., 2020), approximately 10% higher than other western countries.

A review from Dror and Allen (2014) found females consumed fewer dairy products than recommendations. The main determinant of females consuming fewer dairy products was attributed to the belief that it caused weight gain. Adolescents are likely to snack more, consume more fast food, skip meals, and consume meals outside the household more frequently than young children (Das et al., 2017). These dietary patterns and behaviours may suggest why adolescents may not be meeting recommendations for calcium intakes.

Table 2.7. Major Calcium Food Group Contributors in Adolescents from New Zealand and Other Developed Countries.

Study (Year) and Country	Primary calcium food group contributors
SUNDIAL Study (2020) New Zealand (Henderson, 2021)	Milk: • 17% females • 28.4% males Cheese • 13.3% females • 10.8% males Bread • 7.5% females • 7.9% males Bread based dishes • 8.2% females • 5.9% males Non-alcoholic beverages • 8.2% females • 5.6% males Grains and pasta • 5.2% females • 5.3% males Vegetables • 6.6% females • 5% males Dairy products • 5.5% females • 4.7% males
Australian Health Survey (2011-2012) Australia (Australian Bureau of Statistics, 2011)	Milk • Females: 9 - 13 years (26.0%), 14 - 18 years (18.7%) • Males: 9 - 13 years (26.2%), 14 - 18 years (22.9%) Cereal-based products and dishes • Females: 9 - 13 years (15.1%), 14 - 18 years (16.0%) • Males: 9 - 13 years (14.6%), 14 - 18 years (20.6%) Cereal and cereal products • Females: 9 - 13 years (13.3%), 14 - 18 years (12.4%) • Males: 9 - 13 years (13.9%), 14 - 18 years (13.6%) Cheese • Females: 9 - 13 years (8.8%), 14 - 18 years (8.2%) • Males: 9 - 13 years (11.3%), 14 - 18 years (10.9%)

Study (Year) and Country	Primary calcium food group contributors
	Non-alcoholic beverages - Females: 9 - 13 years (6.6%), 14 - 18 years (9.4%) - Males: 9 - 13 years (8.6%), 14 - 18 years (8.6%) Flavoured milks and milkshakes - Females: 9 - 13 years (5.1%), 14 - 18 years (9.1%) Yoghurt - Females: 9 - 13 years (5.1%), 14 - 18 years (3.7%)
Dairy food and nutrient intakes in Australian adolescents (2012) Australia (Parker et al., 2012)	Dairy products high in calcium food sources: Milk (plain, flavoured milk, smoothies), cheese, yogurt. Dairy products contributing to calcium intake (based on a 300 mg calcium dairy serve) <u>At 14 years follow up:</u> - Females: 65% - Males: 68% <u>At 17 years follow up:</u> - Females: 61% - Males: 65%
National Teens Food Survey II (2019-2020) Ireland (Cashman et al., 2022)	Milk and yogurt 27.2% Bread and rolls 16.9% Grains, rice, pasta, and savouries 10.7 Cheeses 8.4% Meat and meat products 7.2% Breakfast cereals 5.2% Sugars, confectionary, preserves and savoury snacks 5.1%
National Teens Food Survey I (2005-2006) Ireland (Irish Universities Nutrition Alliance, 2006)	Main dietary sources of calcium include milk and yogurt, bread and rolls, grains, rice, pasta and savouries, cheeses, and meat and meat products.
National Diet and Nutrition Survey (2008/2009-2011/2012) United Kingdom (Bates et al., 2017)	Cereal and cereal products - Females: 36% - Males: 38% Milk and milk products - Females: 34% (17% from cows' milk, 9% from cheese, 3% from yogurt)

Study (Year) and Country	Primary calcium food group contributors
	• Males: 35% (27% from cows' milk, 8% from cheese, 3% from yogurt) Meat and meat products • Females: 9% • Males: 9% Vegetables and potatoes • Females: 6% • Males: 5% Non-alcoholic beverages • Females: 4% • Males: 4% Sugar, preserves and confectionery • Females: 3% • Males: 3%
Canadian Community Health Survey (2004/2015) Canada (Vatanparast et al., 2020)	2004 • Milk and milk alternatives 47.1% • Grain products 13.3% • Fruits and vegetables 9.6% • Other food and beverages 8% • Meat and meat alternatives 6.3% 2015 • Milk and milk alternatives 41.0% • Grain products 12.7% • Fruits and vegetables 10.5% • Other food and beverages 9.8% • Meat and meat alternatives 6.8%

Abbreviation: %, percentage.

2.9 Summary

Calcium plays an essential role in several parts of the body, particularly bone growth and development. Adequate nutrition provided by diet can contribute to better health outcomes. Extensive literature highlights that adequate calcium intake through the lifecycle, particularly during adolescence, is crucial to help reduce the incidence of osteoporosis later in life. The importance of adequate calcium intake during adolescence is due to the accrual of peak bone mass during adolescence. Many adolescents worldwide, including New Zealanders have not met requirements for daily calcium intake, which may result in developing osteoporosis during later years. Dairy products, in particular milk are the primary food source of calcium in adolescents' diets. This was concluded in both New Zealand and similar developed countries. In the New Zealand diet, other common sources of calcium include bread and calcium-rich non-alcoholic beverages (e.g., tea, coffee, hot chocolate drinks, juices etc.). As the last National Nutrition Survey in New Zealand on adolescents was conducted over 15 years ago (Australian Bureau of Statistics, 2011; Ministry of Health, 2003) results are now outdated. Recent data is required to determine to the current situation regarding adolescents' calcium intakes and dietary sources of calcium.

Chapter 3: Manuscript

3.1 Abstract

Background / Aim

Calcium is an important mineral, particularly during adolescence due to increased growth and development of bone mass. Achieving calcium requirements during adolescence can help reduce the risk of developing osteoporosis later in life. The aim of this study was to assess calcium intake and food sources of calcium of adolescents living in New Zealand.

Methods

Adolescents aged 12 to 18 years old were recruited through intermediate and secondary schools in Auckland, the Waikato and the Bay of Plenty regions of New Zealand. Dietary intake was assessed using Intake24 (an online 24-hour dietary recall) adapted for the New Zealand population. Calcium intake was compared with the Australian New Zealand Nutrient Reference Values and dietary sources of calcium were investigated.

Results

A total of 310 students participated (66.7% female); the majority identified as Māori (30.3%) or New Zealand European (27.7%). Most were aged 16 years (34.2%) or 17 years (36.5%), with a moderate level of socioeconomic disadvantage (43.2%). The median [IQR] daily calcium intake for female adolescents was 482 mg [286, 780], and male adolescents was 463 mg [286, 790]. Rates of inadequate calcium intake based on the estimated average requirement of calcium (< 1050 mg/day for 12- to 18-year-olds) were 88.9% in females (n = 184) and 84.3% in males (n = 86). Savoury mixed dishes contributed the largest amount of total calcium intake in both females and males, providing 25.6% and 23.9% respectively. Additional food sources were milk (13.7% females, 16.5% males); non-alcoholic beverages (18.9% females, 16.3% males); grains, pasta, and cereals (7% females, 8.1% males); bread (8.3% females, 5.8% males); and sweets, desserts, and snacks (7.5% females, 5.8% males).

Conclusions

Calcium intakes among participants in this study were below estimated average requirement indicating a need to promote calcium-rich foods among adolescents. The main dietary sources of calcium included mixed dishes and non-alcoholic beverages. Additional research with two non-consecutive 24-hour recalls is required to further investigate calcium intake throughout the whole of NZ, particularly in younger adolescents, and the context in which calcium is being consumed (time of the day; foods calcium food sources are being consumed with) to better understand the calcium intake in NZ adolescents.

Key Words

Calcium, dietary intake, food sources, adolescents, 24-hour dietary recall, New Zealand.

3.2 Introduction

Adolescence is a time of rapid skeletal growth and development (Das et al., 2017). Achieving adequate calcium intake during adolescence is critical for peak bone mass accrual to reduce the risk of developing osteoporosis later in life (Mesías et al., 2011).

Multiple international studies have found many adolescents are not consuming an adequate intake of calcium from their diet (Australian Bureau of Statistics, 2011; Cashman et al., 2022; Vatanparast et al., 2020). The estimated average requirement of calcium for adolescents aged 12 to 18 years is 1,050mg per day (National Health and Medical Research Council et al., 2006). Findings from the 2002 New Zealand Children's Nutritional Survey found (NZNCNS) 29.6% of females and 28.7% of males aged 11 to 14 years had inadequate intakes of calcium (Ministry of Health, 2003). In the 2008/2009 New Zealand Adult Nutrition Survey (NZANS), 87.8% of females and 57.7% of males aged 15 to 18 years were found to have inadequate calcium intake (University of Otago and Ministry of Health, 2011). There has been limited studies exploring calcium intake in New Zealand adolescents with these national nutrition surveys undertaken over 15 years ago. The SUNDIAL Study (n = 344) conducted in 2020 identified that calcium intake was inadequate for a significant proportion of adolescents

aged 15 to 18 years, 85% of females and 63% of males did not achieve the calcium estimated average requirement (Henderson, 2021).

Dairy products are the predominant food group that contributes to calcium intake. The 2008/2009 New Zealand Adult Nutrition Survey and 2002 National Children's Nutrition Survey observed milk was the most common dietary source of calcium in New Zealand adolescents (Ministry of Health, 2003; University of Otago and Ministry of Health, 2011). For adolescents aged 11- to 14-year-olds, milk contributed 31% in females and 35% in males towards calcium intake (Ministry of Health, 2003). In older adolescents (15 to 18 year olds), milk contributed 18.9% in females and 23.2% of calcium intake in males (University of Otago and Ministry of Health, 2011). Other major food sources of calcium included bread, non-alcoholic beverages (e.g., tea, coffee, hot chocolate drinks, juices), cheese, bread-based dishes, and other dairy products (e.g., yoghurt, ice-cream, sour cream) (Ministry of Health, 2003; University of Otago and Ministry of Health, 2011). Similarly, the SUNDIAL Study indicated milk was a significant contributor of calcium. The main food source of calcium was milk, contributing 17% in females and 28.4% in males (Henderson, 2021). In addition, Henderson (2021) found that cheese (17% and 10.8%), bread (7.5% and 7.9%), bread based dishes (7.5% and 5.9%), non-alcoholic beverages (8.2% and 5.6%), and dairy products (5.5% and 4.7%) in females and males respectively contributed to calcium dietary sources, comparable to those reported from 2008/2009 NZANS and 2002 NCNS.

Since the publication of these studies, calcium intakes and dietary sources of calcium may have changed due to changes to the food environments, changes to dietary patterns (e.g., trends such as increased frequency in snacking and increased preference for ultra-processed food) (González-Monroy et al., 2021), and increased cost of living (Stats NZ Tatauanga Aotearoa, 2022). This study aims to describe calcium intakes and calcium food sources in adolescents aged 12 to 18 years living across the Auckland, Waikato and Bay of Plenty regions in New Zealand.

3.3 Methods

Study Procedure and Participants

This study was carried out as part of a cross-sectional national study; Te Rourou Kai o Ngā Rangatahi: Eating Patterns of Young People in New Zealand. The primary aim of Te Rourou Kai o Ngā Rangatahi: Eating Patterns of Young People in New Zealand study was to identify ultra-processed food consumption in New Zealand (NZ) adolescents. Adolescents in years 7 and above (10 to 18 years old) across schools in the Auckland, Waikato and Bay of Plenty regions were recruited. All schools (excluding kura) were contacted by a senior advisor or nutritionist on the study and invited to participate. Schools were contacted between June and August 2024 via phone, then followed up with a formal invitation via email. Schools who took part were provided with a \$300 voucher.

Recruitment was conducted by convenience sampling prioritising the inclusion of schools that took part in the Ka Ora, Ka Ako lunch program. The Ka Ora, Ka Ako programme is a government-funded lunch programme that provides a free nutritious school lunch to students (years 1 and above). The program targets the top 25% of students in schools who face the greatest socioeconomic barriers, with a goal of reducing food insecurity in New Zealand (Ministry of Education Te Tāhuhu o te Mātauranga, 2024). In 2024, there were 251 schools (with student years 7 and above) participating in the Ka Ora, Ka Ako Programme across the Auckland, Waikato, and Bay of Plenty regions. Data on the assigned Equity Index (EQI) of all participating schools was collected. The EQI is a tool used to allocate equity funding for NZ schools based on socioeconomic factors (Ministry of Education Te Tāhuhu o te Mātauranga, 2024). The EQI aims to reduce the impact from socioeconomic barriers and help support students' achievements. Generally, the higher the EQI number, the more socioeconomic barriers students face.

Inclusion criteria of this study were females and males aged 10 to 18 years who could read English or Māori text. Participants willing to participate were provided with an information sheet and consent form. A copy of the information sheet was sent to parents/guardians of participants younger than 16 years. All participants provided written informed consent, if the participant was under 16 years old parental/guardian consent also was required. Participants

were assigned an identification number, so data remained confidential from data collectors and analyses. Participant information related to identification number was stored separately. Ethical approval for the Te Rourou Kai o Ngā Rangatahi study was approved by Massey University Human Ethics Otu Matatika 1, Application OM23/55. This study was funded by the National Heart Foundation of New Zealand.

Data Collection

Data collection took place between June 2024 and August 2024 (second and third school terms). Research assistants visited the participating schools on the day of data collection and provided instructions to participants prior to data being collected. Each participant was asked to complete a one 24-hour dietary recall from the previous weekday. Te Rourou Kai o Ngā Rangatahi: Eating Patterns of Young People in New Zealand study collected a secondary 24-hour dietary recall on a subset of participants ($n = 63$). However, dietary analysis was only conducted on the first 24-hour dietary recall in this study due to low response rate to follow-up email invitations.

An online questionnaire was filled out for each participant regarding sociodemographic factors. Intake24 applies the multiple pass recall method that allows for an uninterrupted recall of food intake. Both Intake24 and the online questionnaire were self-administered. Participants were able to ask questions from the research assistants who were available during data collection.

Socio-demographic Questionnaire

Socio-demographic characteristics included age, year level, sex, ethnic group(s), use of dietary supplements, and school attended. See Appendix C for a copy of the questionnaire. Dietary supplements were not included in Intake24 therefore did not contribute to dietary or nutrient intake. Data on the school attended was collected to identify participant's equity index and if the school participated in the Ka Ora, Ka Ako programme.

Intake24

Intake24 is an online 24-hour dietary recall tool developed that contains a database of over 2,800 foods which are linked to food composition codes and over 2,500 validated portion size images (Intake24, n.d.). Intake24 collects lists of all food and beverages consumed by the participant, and then participants are probed with questions on type of foods consumed and quantities. The participant is then able to have a final review the food and beverages they have reported to provide an opportunity to add additional or commonly forgotten food and beverages. Data output from Intake24 calculates energy, macronutrients, micronutrients, food groups, and disaggregation variables (e.g., vegetable intake). The Intake24 was evaluated and validated on participants 11 years and older against interview led recalls (Bradley et al., 2016). The Intake24-NZ version was developed by adding a NZ food list that incorporated Māori, Pasifika, and Asian cultural foods and meals (Mackay et al., 2025). In addition, this included generation of new portion size images for additional foods (e.g., NZ specific packaged foods) and inclusions of plant-based meats and milk alternatives (Mackay et al., 2025).

Participants were asked to recall all foods and beverages consumed the previous weekday (from midnight to midnight). Data collection took place between a Tuesday to Friday so data could be collected on a weekday. Questions asked included timing of mealtimes (breakfast, morning snack or drink, lunch, afternoon snack or drink, evening meal, late snack or drinks), the name and portion size of the food and drink consumed. If a food item did not appear on the list, a similar foods item was matched. Information on the portion size of food was referenced through either visual representations or specific measured amounts. Visual representations included various images with common food brands to distinguish amount consumed, referenced using quantities of the food item or in handfuls, or pictures with various quantities of food / related food on a plate, bowl or cup with weight references listed. Specific measured amounts included standard household measures (cup or spoon size). Beverage portion methods were shown as a standard household measure (cup size), or various sizes were referenced (e.g., in a bottle, in a glass, or in a mug).

Participants had the option to select “skip meal” if they missed meals. Subsequent questions were asked about meals to identify if additional foods items were added (e.g., spreads or

sauces). A meal gap question was asked after completing the recall if there was a long period between meals to acknowledge that a meal could have not been entered. Commonly forgotten items were listed at the end of the recall to ensure all food and beverages had been recorded.

Analysis of Data Including Dietary Data

Participants were grouped into prioritised ethnic groupings. Participants who identified themselves as more than one ethnicity were allocated into a single ethnic group in order of priority. The priority order established in New Zealand is by which included Māori, Pasifika, Asian, other (e.g., Middle Eastern/Latin American/African), and New Zealand European.

All data from Intake24 were quality checked by research assistants. Intake24 is linked to a New Zealand food composition code to analyse types of foods and nutrients. Energy intake was expressed as kilojoules (kJ). Calcium intake was expressed in milligrams per day (mg/day).

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 29.0.2.0 (IBM Corp, 2022). Descriptive analyses included the total study population, sociodemographic, and dietary supplement use which was gathered from questionnaire data. Categorical data was presented as number and percentages. A chi-squared test was used for categorical data. To provide complementary measures of central tendency, both means and medians were reported. The mean reflecting the overall average, whilst the median offers a robust estimate which is less influenced by skewed data and outliers. A *p*-value of < 0.05 was considered statistically significant. Independent t-tests and Mann-Whitney tests were used as appropriate.

3.4 Results

3.4.1 Study Participants

Participants from 16 different intermediate and secondary schools took part in this study, with 355 participants completing the study with full data sets. Participants who were < 12 years or > 18 years old were excluded from the analysis. Participant's energy intake > 3,500 kilocalorie (kcal) (>14,644 kJ) in females and > 4,000kcal (> 16,736 kJ) in males were excluded as it was considered implausible (Willett, 2012). Obvious errors in participants' data were excluded from the analysis such as an implausible portion size or missing data. A total of 310 participants were included in the final analysis. One participant who did not specify a sex was excluded from the dietary analysis to ensure the research aligned with stated objectives of comparing males and females' calcium intake.

3.4.2 Participant Demographics

Sociodemographic characteristics of participants are presented in Table 3.1. Out of 310 participants, 207 (66.7%) were female, 102 (33.0%) were male, and 1 (0.3%) participant did not disclose their sex. Māori was the most reported ethnicity with 30.3% of participants, 27.7% identified as New Zealand European, 21.0% identified as Pasifika (including Cook Islands Māori, Niuean, Tongan, and Samoan), 14.8% identified as Asian (including Indian), and 6.1% identified as belonging to a different ethnicity. Participants level of socioeconomic disadvantage was classified by the school's equity index (EQI). A total of 31.9% of participants had low socioeconomic disadvantage, 43.2% had moderate socioeconomic disadvantage, and 24.8% had high socioeconomic disadvantage. Supplement use in participants was 29.4% (n = 91). The type and calcium content from supplements was not established, as the primary focus was calcium obtained from food sources.

Table 3.1: Socio-demographics of Participants

Demographic characteristics of participants		n (%)
n		310
Age (years)		
	12	4 (1.3)
	13	20 (6.5)
	14	33 (10.6)
	15	18 (5.8)
	16	106 (34.2)
	17	113 (36.5)
	18	16 (5.2)
Sex		
	Female	207 (66.7)
	Male	102 (33.0)
	Prefer not to say	1 (0.3)
Ethnicity*		
	Māori	94 (30.3)
	New Zealand European	86 (27.7)
	Pasifika	65 (21.0)
	Asian	46 (14.8)
	Other	19 (6.1)
Level of socioeconomic disadvantage (based on the EQI)		
	Low	99 (31.9)
	Moderate	134 (43.2)
	High	77 (24.8)
Usage of supplements (any kind)		
	No supplement use	219 (70.6)
	Supplement use	91 (29.4)

Abbreviations: EQI, equity index; %, percentage.

* Participants who identified as more than one ethnicity were organised into prioritised ethnicities. Available in the appendix, Table 5.

3.4.3 Dietary Analysis

Adolescent females and males consumed comparable dietary calcium intake ($p = 0.845$). The mean $\pm$ SD (95% CI) intake of dietary calcium was 576 ± 419 mg (518.5, 633.4) in females and 586 ± 444 mg (498.9, 673.3) in males. The median [IQR] of calcium intake in females was 482 mg [286, 780], and 463 mg [286, 790] in males.

The rate of calcium inadequacies in adolescents of ≤ 1050 mg/day assessed against the New Zealand EAR for calcium (National Health and Medical Research Council et al., 2006) was not statistically significant between females and males ($p = 0.255$). A total of 88.9% ($n = 184$) of females and 84.3% ($n = 86$) of males had inadequate calcium intakes. Daily energy intake was observed to be significantly higher in males than females ($p = 0.05$). Mean $\pm$ standard deviation (SD) daily energy intake in females was 6548 ± 3234 kJ and 7748 ± 4019 kJ in males. Table 3.2 below presents the dietary analysis of energy intake, calcium intake and rate of inadequate calcium intake of participants.

Table 3.2: Energy Intake, Calcium Intake, and Prevalence of Calcium Inadequacy in New Zealand Female and Male Adolescents*.

		Dietary energy intake (kJ/day)			Dietary calcium intake (mg/day)				Inadequate calcium intake ¹ (National Health and Medical Research Council et al., 2006) ($< 1,050$ mg/day for 12 to 18 year olds)
Sex	n (%)	Mean $\pm$ SD	Median	IQR	Mean $\pm$ SD	(95% CI)	Median	IQR	n (%)
Females	207 (66.7)	6,548 $\pm$ 3,234	6,339	[3908, 9070]	576 $\pm$ 419	(518.5, 633.4)	482	[286, 780]	184 (88.9)
Males	102 (33.0)	7,748 $\pm$ 4,019	7,254	[4772, 10654]	586 $\pm$ 444	(498.9, 673.3)	463	[286, 790]	86 (84.3)
<i>P value</i>		<i>Independent T test: p = 0.05</i>			<i>Independent T test: p = 0.845</i>		<i>Mann-Whitney U test: p = 0.941</i>		<i>Chi-squared test: p = 0.255</i>

Abbreviations: EAR, estimated average intake; IQR, interquartile range; SD, standard deviation. P value < 0.05 was considered statistically significant.

¹ Inadequate calcium intake was based on the estimated average requirement of calcium for 12 to 18 year olds.

* The participant who selected sex as “prefer not to say” are not included in this table.

3.3.4 Dietary Sources of Calcium

Table 3.3 presents dietary sources of calcium and their total contribution to calcium intake in NZ adolescents, expressed as mean percentage contribution (95% CI), median calcium intake (mg/day), and IQR. A full list of food sources included in each food group is provided in Appendix A. Non-alcoholic beverages (n = 290); savoury mixed dishes (n = 210); sweet, desserts, or snack foods (n = 189); and grains, pasta, or cereals (n = 182) throughout the day were the food groupings consumed by most participants. The food groups that contributed the greatest total calcium intake across the day were savoury mixed dishes e.g., pasta and rice dishes, burgers, pizza, filled sandwiches (24.5%, (CI 21.4, 27.6)). This was followed by non-alcoholic beverages (18.2%, CI (15.8, 20.6)), and milk and milk products (14.6%, CI (11.8, 17.4)). Sweets, desserts and snack foods; bread; and grains, pasta or cereals contributed approximately 7% each to calcium intake. Dairy products and dairy product alternatives; cheese and cheese products; meat and meat products; and vegetables contributed around 4% each to calcium intakes. Lowest contributions to total calcium intake from food groups were fruit (2.5%, CI (1.6, 3.3)); and cooking ingredients and condiments (1.2%, CI (0.6, 1.7)). Savoury mixed dishes contributed a median of 71.1 mg/day [IQR 0, 189.1] mg / day, with non-alcoholic beverages (31.6 mg/day [IQR 16.9, 96.0]) contributing half of that of savoury mixed dishes.

Table 3.3: Calcium Dietary Sources in New Zealand Adolescents

	Adolescents (n = 310)				
	Contribution of total calcium from food group		n	Contribution of food groups to participants calcium intake	
	Mean	95% CI		Median (mg/day)	IQR
Savoury mixed dishes	24.5%	(21.4, 27.6)	210	71.1	[0, 189.1]
Non-alcoholic beverages	18.2%	(15.8, 20.6)	290	31.6	[16.9, 96.0]
Milk and milk alternatives	14.6%	(11.8, 17.4)	103	0	[0, 232.9]
Sweets, desserts and snack foods	7.6%	(6.0, 9.2)	189	6.9	[0, 37.5]
Bread	7.5%	(5.9, 9.1)	124	0	[0, 57.6]
Grains, pasta, and cereals	7.3%	(5.8, 8.9)	182	5.1	[0, 30.6]
Dairy products and dairy product alternatives	4.5%	(3.1, 6.0)	50	0	[0, 0]
Cheese and cheese products	4.4%	(3.0, 5.8)	44	0	[0, 0]
Meat	4.0%	(2.8, 5.1)	139	0	[0, 12.9]
Vegetables	3.7%	(2.7, 4.7)	128	0	[0, 16.6]
Fruit	2.5%	(1.6, 3.3)	106	0	[0, 9.8]
Cooking ingredients and condiments	1.2%	(0.6, 1.7)	136	0	[0, 3.1]

Abbreviations: IQR, interquartile range; 95% CI, 95% confidence intervals.

Table 3.4 below presents dietary calcium sources in female and male adolescents. Calcium sources in females were primarily derived from the following; savoury mixed dishes (23.8%, 58.8 [0, 188.8] mg/day); non-alcoholic beverages (19.0%, 37.5 [18.0, 100] mg/day); milk and milk alternatives (13.8%, 0 [0, 117.0] mg/day). Further contributions to dietary calcium were bread (8.3%, 0 [0, 60.5] mg/day) sweets, desserts and snack foods (8.1%, 10.4 [0, 40.2] mg/day), grains, pasta, and cereals (7.1%, 5.1 [0, 32.2] mg/day). Similarly, males' primary source of dietary calcium was savoury mixed dishes (25.9%, 86.7 [0, 190.2] mg/day), non-alcoholic beverages (16.5%, 28.5 [15.9, 80.0] mg/day), milk and milk alternatives (16.4%, 0 [0, 304.9] mg/day), and grains, pasta and cereals (8.0%, 5.2 [0, 28.3] mg/day). Dairy products and dairy product alternatives; cheese and cheese products; meats; vegetables; fruit; cooking ingredients and condiments all minimally contributed to total calcium percentages in both females and males.

Savoury mixed dishes were a greater source of dietary calcium in males (86.7 [0, 190.2] mg/day) than females (58.8 [0, 188.8] mg/day). Grain, pasta and cereal contributed similar amounts of calcium in males (8%, 5.2 [0, 28.3] mg/day) and females (7.1%, 5.1 [0, 32.2] mg/day). Females' contribution to total calcium from cheese and cheese products ((5.2%) (CI 3.4, 7.1)) was almost double the amount than males ((2.8%) (CI 0.8, 4.8)). In contrast, meat contributed twice the amount of total calcium in males ((6.6%), CI 3.7, 9.4)) as in females ((2.7%), CI 1.7, 3.6)).

Table 3.4: Calcium Dietary Sources in New Zealand Female and Male Adolescents*

	Females (n = 207)					Males (n = 102)				
	Contribution of total calcium from food group		n	Contribution of food groups to participants calcium intake		Contribution of total calcium from food group		n	Contribution of food groups to participants calcium intake	
	Mean	95% CI		Median (mg/day)	IQR	Mean	95% CI		Median (mg/day)	IQR
Savoury mixed dishes	23.8%	(20.2, 27.5)	138	58.8	[0, 188.8]	25.9%	(20.1, 31.7)	71	86.7	[0, 190.2]
Non-alcoholic beverages	19.0%	(15.9, 22.0)	194	37.5	[18.0, 100]	16.5%	(12.6, 20.5)	95	28.5	[15.9, 80.0]
Milk and milk alternatives	13.8%	(10.4, 17.2)	69	0	[0, 117.0]	16.4%	(11.3, 21.4)	34	0	[0, 304.9]
Sweets, desserts and snack foods	8.1%	(6.1, 10.2)	138	10.4	[0, 40.2]	6.6%	(4.1, 9.0)	51	0.1	[0, 33.2]
Bread	8.3%	(6.3, 10.4)	92	0	[0, 60.5]	5.8%	(3.2, 8.4)	32	0	[0, 30.2]
Grains, pasta, and cereals	7.1%	(5.3, 8.8)	125	5.1	[0, 32.2]	8.0%	(4.9, 11.1)	57	5.2	[0, 28.3]
Dairy products and dairy product alternatives	4.8%	(3.0, 6.6)	35	0	[0, 0]	4.2%	(1.8, 6.5)	15	0	[0, 0]
Cheese and cheese products	5.2%	(3.4, 7.1)	37	0	[0, 0]	2.8%	(0.8, 4.8)	8	0	[0, 0]
Meat	2.7%	(1.7, 3.6)	87	0	[0, 9.6]	6.6%	(3.7, 9.4)	52	1.2	[0, 20.3]

Vegetables	3.4%	(2.4, 4.4)	90	0	[0, 16.9]	4.2%	(1.9, 6.6)	38	0	[0, 14.0]
Fruit	2.8%	(1.6, 3.9)	85	0	[0, 12.1]	1.9%	(0.6, 3.1)	21	0	[0, 0]
Cooking ingredients and condiments	1.0%	(0.3, 1.7)	93	0	[0, 3.2]	1.1%	(0.5, 1.8)	42	0	[0, 3.2]

Abbreviations: IQR, interquartile range; 95% CI, 95% confidence intervals; %, percentage.

* The participant who selected sex as “prefer not to say” are not included in this table.

3.5 Discussion

3.5.1 Summary of Results

Findings of this research have identified adolescents aged between 12 and 18 years in the study sample have low rates of calcium adequacy. Mean $\pm$ SD daily calcium intake for males and females was 586 ± 444 mg and 576 ± 419 mg respectively. Overall, 88.9% of females and 84.3% of males had inadequate calcium intakes as based on the Australia and New Zealand Nutrient Reference Value of estimated average requirement. This suggests most adolescents in the Auckland, Waikato and Bay of Plenty regions of NZ are not consuming enough calcium to meet requirements. Mean $\pm$ SD of daily energy intake in females was 6548 ± 3234 kJ and 7748 ± 4019 kJ in males.

The main dietary calcium food sources that contributed to calcium intake for adolescents were savoury mixed dishes, non-alcoholic beverages, and milk & milk alternatives. Savoury mixed dishes ($n = 210$) and non-alcoholic beverages ($n = 290$) contributed the largest amount of calcium to adolescents' diets, with a combined calcium contribution total of 42.7% towards calcium intake. This suggests adolescents are achieving most of their calcium requirements at mealtimes and through beverages, rather than at snack time. Food groups contributing less than 10% of calcium intake include sweets, desserts and snack foods; bread; grains, pasta, and cereals; dairy products and dairy product alternatives; cheese and cheese products; meat; vegetables; fruit; and cooking ingredients and condiments. Only a few participants consumed dairy products & dairy alternatives ($n = 50$) and cheese & cheese products ($n = 44$), likely due to participants consuming them in mixed dishes.

3.5.2 Calcium Intake Compared with the Recommendations

This study shows a high proportion of adolescents living in the Auckland, Waikato and Bay of Plenty regions of New Zealand are not currently meeting the EAR of daily calcium intake (1050 mg/day). In comparison with prior NZ surveys, calcium intake in this study was lower in both males and females. Young NZ adolescents (aged 11 to 14 years) with inadequate calcium intake in the 2002 National Children's Nutrition Survey was 28.7% of males and

29.6% of females (Ministry of Health, 2003). Inadequate rates of calcium intake in older NZ adolescents (aged 15 to 18 years) was 57.7% of males and 87.8% of females in the 2008/09 New Zealand Adult Nutrition Survey, 63% of males and 85% of females in the SUNDIAL Study (Henderson, 2021; University of Otago and Ministry of Health, 2011). This suggests adolescents' calcium intake could be declining relative to previous years. Multiple 24-hour dietary recalls from participants may provide a more accurate mean daily calcium intake.

The New Zealand National Children's Nutritional Survey mean daily calcium intake for young adolescents was 888 mg in males and 733 mg in females (Ministry of Health, 2003). The New Zealand Adult Nutrition Survey mean daily calcium intake in older adolescents was 1035 mg in males and 724 mg in females University of Otago and Ministry of Health (2011). More recently, Henderson (2021) noted NZ males mean daily calcium intake was 893 mg in 15- to 16-year-olds and 941 mg in 17- to 18-year-olds. Furthermore, NZ females daily calcium mean intake was 752 mg in 15- to 16-year-old and 677 mg in 17- to 18- year-old (Henderson, 2021). Collectively, females are less likely to meet daily calcium requirements than males which could be a result of lower energy intake (Cashman et al., 2022).

3.5.3 Food Sources of Calcium

Attention should be drawn to how calcium food sources are grouped differently between research studies. While findings of major calcium dietary food sources from this study generally align, food groups cannot be directly compared. Calcium contribution across the 12 food groups established in this study varied considerably due to the nature of the wider study. Dairy products and dairy product alternatives included both high-calcium sources (e.g., yogurt) and low-calcium sources (e.g., coconut cream). The online diet recall method, Intake24 generalised some foods and assumed ingredients. Similar research on calcium food groups used methodologies that were often completed through multiple diet recalls therefore gathering specific detail regarding food ingredients and specific quantities.

Calcium from non-alcoholic beverages contributed 18.2% of total calcium intake, which is double that of recent NZ studies, 2008/09 NZANS (University of Otago and Ministry of Health, 2011), 2002 NCNS (Ministry of Health, 2003), and Dunedin Study (Henderson, 2021).

Non-alcoholic beverages in this study included; Soft drinks, flavoured water, juice, cordial, fruit drinks, Coffee, tea, energy drinks, protein drinks, sports drinks, and meal replacement drinks. Refer to Table 4 in the Appendix for a complete list of classifications of each food group. The Dunedin Study, 2002 NCNS, and 2008/09 NZANS classified dietary supplements including meal replacements into another food group, which could account for some of differences in calcium contributed from non-alcoholic beverages (Henderson, 2021; Ministry of Health, 2003; University of Otago and Ministry of Health, 2011). Furthermore, Milk and milk alternatives (14.6%) contributed less to calcium intake than other NZ studies in adolescents (Henderson, 2021; Ministry of Health, 2003; University of Otago and Ministry of Health, 2011). Bread was a notable contributor of calcium in New Zealand unlike international studies. In New Zealand, calcium fortification in bread products is voluntary (Ministry of Primary Industries (MPI), 2012).

3.5.4 Strengths of the Study

The strengths of the study were the inclusion of a variety in ethnic groups that took part, including a high number of Māori and Pasifika participants who are often underrepresented in New Zealand research. Furthermore, schools included in the study had a variety of equity index scores to provide estimations of participants socioeconomic disadvantage level. The use of the online dietary recall tool (Intake24) allowed participants to be less burdened as it was quick and simple to use. Intake24 included many New Zealand specific foods (Mackay et al., 2025) which allowed a more accurate estimate of nutrients as foods were automatically linked to nutrient lines rather than being manually matched by nutritionists.

3.5.5 Limitations of the Study

A representative study of New Zealand adolescents would help provide further clarity on calcium intake and calcium dietary food sources. This includes investigating younger adolescents aged 10 to 11 years and adolescents who are outside of the regions of Auckland, Waikato and Bay of Plenty which was investigated in this study. Over-reporters were considered in the analysis of the data, however under-reporters were not assessed. Underreporting is common in dietary assessment methods particularly in adolescents

(Bandini et al., 1990; Jones et al., 2021; Sichert-Hellert et al., 1998) and could have resulted in underestimation of calcium intake and calcium food group contribution.

Due to a high rate of Māori and Pasifika participants taking part, it is likely that there is an overrepresentation of this ethnic group compared with the general New Zealand population. This overrepresentation rate of the Māori population could be explained by the schools in the regions of New Zealand where the study took place having high groups of Māori representation.

The context of eating (timing of eating and pattern of foods etc.) is necessary to look at calcium intake in more detail. This would facilitate an understanding of patterns of eating in adolescents and support interventions to improving calcium intake in New Zealand adolescents. A secondary 24-hour dietary recall should be considered to better determine day-to-day variance of calcium intake in an adolescent's diet to provide data to more accurately represent usual intake (Biró et al., 2002; Ma et al., 2009; Shamah-Levy et al., 2016). Gathering more information on calcium intake including supplement use and special diets (dairy-free, vegan, or vegetarian) are an important consideration when identifying calcium in adolescents' diets as restrictive diets that eliminate dairy products can have lower calcium intakes (Bakaloudi et al., 2021; Craig, 2009). As savoury mixed dishes were the food group that contributed the largest proportion of calcium in New Zealand adolescents, further details on food components or ingredients in dishes are required to identify exact food sources of calcium. Due to the topic of the wider study and the use of an online dietary recall tool, savoury mixed dishes was a generalised food grouping.

3.5.6 Conclusion

Findings of this research have identified 12 to 18 years in New Zealand have low rates of dietary calcium intake and many adolescents are not meeting the New Zealand estimated average requirement for daily calcium intake. Major dietary food sources that contribute to calcium intake in NZ adolescents include savoury mixed dishes, non-alcoholic beverages, and milk and milk alternatives. Ultimately, this research demonstrates the need for concern within this study population due to the low calcium consumption in adolescents which may

be associated with osteoporosis later in life. To conclude, the study supports the initial hypothesis and highlights the importance of further studies on New Zealand adolescents regarding calcium intake and dietary sources of calcium.

Chapter 4: Conclusions and Recommendations

4.1 Summary

This research set out to; assess calcium intake in adolescents with an electronic 24-hour dietary recall using the multiple pass method, to determine if New Zealand (NZ) adolescents met recommendations for calcium intake, and to evaluate food sources of calcium in adolescents' diets. Calcium intake and calcium dietary sources were collected via an electronic 24-hour dietary recall using Intake24. Research was collected on adolescents aged 12- to 18-year-olds living in Auckland, Bay of Plenty, and Waikato areas of NZ.

Findings from this study suggested most males and females mean calcium intake was low and insufficient to meet the estimated average requirement (EAR). Over 80% of adolescents had calcium intakes below the EAR (88.9% and 84.3% in females and males respectively). When compared against previous research conducted in NZ, this study had lower calcium intakes and higher rates of calcium inadequacies in females and males (Henderson, 2021; Ministry of Health, 2003; University of Otago and Ministry of Health, 2011). Calcium intake and the rate of inadequate calcium intake in comparison to other developed countries was found to be slightly higher (Australian Bureau of Statistics, 2011; Bates et al., 2017; Cashman et al., 2022; Department of Health and Ageing, 2008; Irish Universities Nutrition Alliance, 2006; Parker et al., 2012; Vatanparast et al., 2020). Calcium food sources in adolescents were primarily derived from savoury mixed dishes (24.5%), non-alcoholic beverages (18.2%), and milk and milk alternatives (14.6%). Females and males had similar percentage contributions of total calcium from all food groups.

This research is important for identifying the risk of inadequate calcium intake during a critical time for bone growth and development. Not achieving adequate calcium intake particularly during adolescence has been attributed to lower peak bone mass being achieved and an increased prevalence of developing osteoporosis later in life (Weaver et al., 2016). This research gathered provides the most current evidence regarding calcium intake and dietary food sources of calcium of adolescents living in NZ until further national nutritional surveys are conducted.

4.2 Study Strengths

Strengths of the study included the sample size being diverse and large with over 300 adolescents from various levels of socioeconomic disadvantages. A large representation of Māori and Pasifika ethnicities were collected in this study. There are currently limited studies regarding calcium intake in Māori and Pasifika adolescents in NZ. This large sample size of Māori and Pasifika ethnicities could also be seen as a potential limitation due to Māori populations and Pasifika populations likely over-representative of the total New Zealand population, likely attributed to the regions in New Zealand from which the data was collected from. In the 2023 NZ census, 17.8% of New Zealanders identified as Māori and 8.9% identified as Pasifika in NZ which is significantly higher than the sample size of this study (Stats NZ Tatauanga Aotearoa, 2024).

A subsequent strength is the research assistants involved were all qualified nutritionists and informed of standardised procedures for collection to ensure streamlined data collection with Intake24. The research assistants were able to provide support to participants regarding any food or nutrient specific question. Intake24 is automated way to collect 24-hour dietary recalls therefore reducing interviewer bias. The multiple pass method on Intake24 provides more opportunities for participants to add initially forgotten food items as diet recalls rely on participants memory. Intake24 has been adapted to include several New Zealand specific foods and brands including a cultural database, therefore making it a suitable dietary tool to be used in this research as its tailored for the population.

4.3 Study Limitations

Due to the wider study Te Rourou Kai o Ngā Rangatahi: Eating Patterns of Young People in New Zealand food grouping of calcium sources, in some categories such as the savoury mixed dishes it was difficult to identify the specific food contributing to calcium as it was so broad. Food groups were categorised after the data was collected, therefore not directly segregated by calcium food type contributor as observed in dairy products and dairy product alternatives group with yogurt and coconut cream grouped together. The categories of the

calcium food group contributors (milk and milk alternatives; dairy products and dairy alternatives) made it difficult to distinguish if dairy, a naturally high sources of calcium was the main contributor towards calcium intake or if calcium fortified products were more prevalent. In addition, cow's milk was in the same category as calcium fortified non-dairy milks. Having food grouping categories specific to calcium contribution source would allow calcium sources to be clearly identified, and so data could be compared directly against similar research published on dietary sources of calcium in adolescents.

A possible limitation whilst using Intake24 includes discrepancies in an estimated portion sizes of each component within a mixed dish served together (e.g., beef stew with rice) thereby potentially impacting the accuracy of nutrient intake. To obtain a more reliable estimate of usual calcium intake and sources, future research should use multiple non-consecutive 24-hour dietary recalls (including both weekdays and weekend days) to account for day-to-day variation in dietary intake. The multiple non-consecutive 24-hour dietary recalls should also consider participant burden, time requirements, and response rates. Participants were not asked in the questionnaire if their 24-dietary recalls reflected their usual dietary intake. Moreover, comparing dietary intake between seasons would provide a more accurate estimation of adolescent's calcium intake and calcium sources as diet varies between seasons due to availability of foods.

Adolescents frequently misreport dietary intake that take part in dietary assessment studies that is self-reported data (Bandini et al., 1990; Jones et al., 2021; Sichert-Hellert et al., 1998). This study accounted for the over-reporters of dietary intake in the analysis of data, however under reporters were not assessed. This reporting error made it hard to distinguish accurate calcium intake and dietary sources of calcium.

4.4 Recommendations and suggestions for future research

This study highlights the need for further research of calcium intake and dietary sources in adolescents. Based on the findings of this study, interventions can be identified and

implemented into public health nutrition initiatives and government initiatives. Currently, the “KickStart Breakfast” is a public health nutrition initiative that provides breakfast (Sanitarium Weet-Bix and milk) to school students. The Kickstart breakfast could be implemented at more schools. Information regarding whether the participating schools in this study had access to the KickStart Breakfast programme was not determined. However, future research should compare participants’ dietary recalls with breakfast and lunch menus provided by their schools on the day of assessment. Government initiatives such as Ka Ora, Ka Ako - Healthy School Lunches Programme that provides school lunches should include a calcium-rich based dishes (e.g., milk, cheese or yogurt-based dishes) to allow more opportunities for adolescents in NZ to reach calcium intake requirements. Calcium-rich food sources should come from a variety of calcium sources, which contribute to overall better health outcomes adolescents and many years after.

Future research should consider being replicated with a larger or national sample of adolescents collecting data on all regions of NZ. Specifically, a sample size that includes younger adolescents aged 10 and 11 years to include the whole adolescent range group, together with a more equal distribution of participants in each age group. Furthermore, a more even distribution of males and females. Finally, a selection of ethnicities that represents all New Zealand population, as it is likely Māori and Pasifika ethnicities was over-represented in this study.

To better understand these results, future studies could address current dietary patterns in adolescents to understand food choices and investigate calcium intake over a prolonged period. Furthermore, calcium intake in the context in which calcium is being consumed (time of the day; foods calcium food sources are being consumed with which could impact the bioavailability or absorption of calcium) to gain a better understanding of the current calcium intake in New Zealand adolescents. Understanding the current dietary sources of calcium among New Zealand adolescents can help identify and address gaps to inform strategies that support NZ adolescents to meet calcium intake recommendations. Clearly defined food group categories may help identify opportunities to add calcium to, or fortify, commonly consumed low-calcium products, thereby supporting adolescents to meet daily calcium intake recommendations.

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Appendices

Appendix A – Supplementary Methods

Table 4: Foods Included in Food Groups that Contribute to Total Calcium Intake of Participants

Food Group	Description
Milk and milk alternatives	Milk, milk alternatives (soy, oat, rice, almond), milk powders, milkshakes, and smoothies.
Cheese and cheese products	Cheese and cheese products (including hard cheese, medium cheese, soft cheese, dairy alternatives, processed cheeses, other types of cheese (e.g., goat and sheep cheese).
Dairy products and dairy product alternatives	Ice cream, ice-cream alternatives, yogurts (including dairy alternatives), cream (including coconut cream), custard, and dairy based desserts.
Savoury mixed dishes	Pasta dishes, rice dishes, sushi, dumplings, rice paper rolls, steamed buns, soup, egg dishes, burgers, pizza, Mexican dishes, filled sandwiches, filled rolls, filled wraps, pastries.
Non-alcoholic beverages	Soft drinks, flavoured water, juice, cordial, fruit drinks, Coffee, tea, energy drinks, protein drinks, sports drinks, and meal replacement drinks.
Vegetables	All types of vegetables (fresh, frozen, canned, cooked, dried), legumes, beans, pulses, tofu, and protein-based meat alternatives.
Fruit	All fruit - fresh, canned, frozen, cooked, and dried.
Meat and meat products	Chicken, beef, pork, fish, seafood, ham, bacon, sausage, canned meat.
Sweets, desserts and snack foods	Sugar, jam, spreads, toppings, chocolates, lollies, confectionary, ice blocks, sorbet, gelato, cakes,

	pancakes, desserts, muesli bars, bliss balls, energy bars, chips, popcorn, savoury snacks, nuts and seeds.
Bread	All types of bread – rolls, bagels, flat bread, wraps. Pita bread, English muffins, crumpets, savoury bread, and scrolls.
Grains, cereals and pasta	Rice, pasta, noodles, couscous, quinoa, breakfast cereals, biscuits, crackers.
Cooking ingredients and condiments	Savoury sauces, condiments, gravy, stock, other cooking ingredients.

Appendix B - Supplementary Results (tables not included in the manuscript)

Table 5: Participants' Ethnicity Groups they Identified with and Prioritised Ethnicity Grouping Ranked (Ministry of Education Te Tāhuhu o te Mātauranga, 2021)

Ethnicity	Identified	Prioritised
Māori	94	94 (30.3%)
New Zealand European	143	86 (27.7%)
Pasifika	138	65 (21.0%)
Asian	48	46 (14.8%)
Other	30	19 (6.1%)

Appendix C - Socio-demographic Questionnaire

What is the Participant ID number you were given?

What school do you attend?

What is your age?

What year level are you at school?

What was your sex at birth (for example, what was recorded on your original birth certificate)?

- Male
- Female
- Prefer not to say

What is your gender?

- Male
- Female
- Prefer not to say
- Other, please enter below

What ethnic group(s) do you belong to? (select all that apply)

- New Zealand European
- Māori
- Samoan
- Cook Islands Māori
- Tongan
- Niuean
- Chinese
- Indian
- Other e.g., Dutch, Japanese, Tokelauan

Do you take any dietary supplements regularly? (select all that apply)

- No
- Iron
- Vitamin C
- Probiotic
- Magnesium
- Protein powder
- Other, please enter below